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THE SHERRITT GORDON COPPER–ZINC DEPOSIT, NORTHERN MANITOBA.[1]

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INTRODUCTION.

THE Sherritt Gordon mine is in the northern part of the province of Manitoba, approximately fifty miles northeast of the Flin Flon ore body now being developed by the Hudson's Bay Mining and Smelting Company. Its discovery came as a result of the impetus given to prospecting by the solving of the metallurgical problems of the southern body and the decision to proceed with its active development.

Flin Flon has been known since 1915 and the Mandy property four miles from it produced high grade copper ore between 1916 and 1920. As a result the Indians who trapped in the country to the north were familiar with the appearance of sulphide gossan, and, with the renewal of interest in mineral deposits in northern Manitoba, prospectors soon began to make use of the knowledge of Indians and of white trappers. The result was the location of the Sherritt Gordon vein, a short distance east of Kississing Lake.

GENERAL GEOLOGY.

General Relations.—The geology of the area surrounding Kississing Lake is quite different from that in the vicinity of Flin Flon. The Mandy and Flin Flon ore bodies are in basic

[1] Presented before the Society of Economic Geologists, New York meeting, Dec., 1928.

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volcanic rocks to which the name, Amisk series, has been given.[2] Lithologically they are similar to the Keewatin rocks of the Lake of the Woods district. They are pre-Cambrian in age and are the oldest rocks recognized in the region. At the Sherritt Gordon Mine the rocks are well banded gneisses of various types

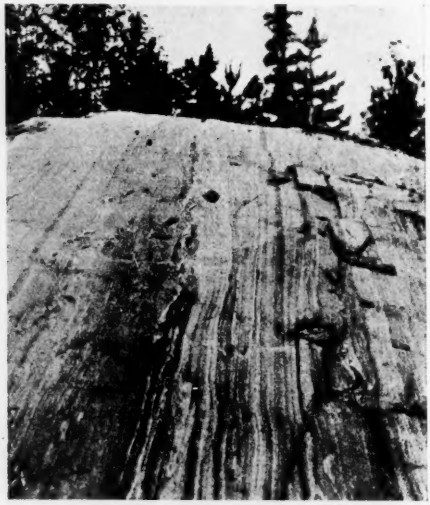

FIG. 1. Banded gneisses.

(Fig. 1). The contact between the greenstones of the volcanic group and the gneisses of the northern area is difficult to locate satisfactorily. Rocks which appear in the field as schists formed by the alteration of the lavas prove to be basic gneisses composed of quartz and actinolite. In the hand specimen the only difference that can be noticed is a silky luster that seems to be typical of the dark rocks assigned to the gneisses, whereas the foliated rocks derived from the alteration of the lavas have the dull green of chlorite.

[2] Geol. Surv. of Canada, Mem. 105.

Lithology of the Gneisses.—A specimen of this extremely basic gneiss, showing no very marked banding in the hand specimen, appears in thin section as a decidedly foliated rock with alternate bands with greater and less proportions of basic minerals. The dark bands are rich in an amphibole, probably actinolite in composition. The crystals lack good outlines but are roughly cigar shaped with a tendency to parallelism of the long axes. Lying among the actinolite individuals are grains of quartz and a little feldspar. The actinolite encloses grains of quartz. The lighter bands consist almost entirely of quartz and feldspar in a mosaic arrangement. Both orthoclase and plagioclase are present.

The gneisses farther north differ chiefly in coarseness of texture and the somewhat greater proportion of quartz. Some bands, however, contain a considerable quantity of dark colored minerals and locally those beds have been referred to as quartz diorites. Many of them have a high content of pink garnet. Specimens were taken from different bands in a width of 100 feet across the strike of the gneisses immediately north of the east shaft of the Sherritt Gordon Mine. The first band exposed north of the shaft is a speckled grey gneiss containing garnet. Under the microscope the rock appears completely crystalline with abundant quartz, amphibole and plagioclase. Some orthoclase and biotite are present. Sericite occurs as an alteration product but is not abundant. Some of the quartz forms areas of interlocking crystals similar to the mosaics to be seen in a quartzite. Some is enclosed in the amphibole, which does not show good crystal outline but seems to grow around the quartz. The plagioclase is apparently a basic variety near labradorite in composition. Tiny, rather rounded apatite crystals occur in the feldspar. The garnets, light pink in color, do not show good crystal outlines and contain particles of quartz. The abundance of quartz, the later crystallization of the amphibole, and the unusual basicity of the feldspar in the presence of so much quartz, are taken as points of evidence favoring a sedimentary origin for this rock.

A specimen taken from a bed a few feet north of this is similar but somewhat lighter in color. Amphibole is present in smaller

amounts and quartz is more abundant. The feldspar is more basic than in the specimen just described.

A specimen taken one hundred feet north of the first contains abundant quartz, plagioclase which is near oligoclase in composition, orthoclase, some biotite, and some microcline. The composition and texture are very like those of a biotite granite but the feldspars are interstitial rather than the quartz, and the biotite also occupies areas between quartz grains as if it had crystallized later than the quartz. For these reasons as well as its association in this bedded series this rock also is believed to be a very thoroughly recrystallized arkosic sediment.

Other specimens from the drill cores were examined microscopically. A grey, garnetiferous gneiss appears in thin section as a thoroughly recrystallized rock in which the most abundant mineral is quartz, much of it in rounded grains. In other areas the quartz forms a mosaic with biotite foils separating some of the quartz individuals. Light pink garnet is abundant. It shows no crystal outlines. Within the garnet are numerous inclusions of rounded quartz grains and grains of magnetite. There is a slight alteration to chlorite. Plagioclase is abundant in this gneiss, and the extinction angles as measured from the albite twinning indicate either albite or a variety between andesine and labradorite. It is quite fresh and apparently secondary. The biotite is strongly pleochroic. It occurs in foils many times as long as they are thick, and probably, therefore, formed under differential pressure (Fig. 2).

A very highly garnetiferous variety from a drill core contains abundant amphibole and plagioclase in addition to the usual light pink variety of garnet. Some quartz and a little biotite are present. The extinction angles in the plagioclase perpendicular to the albite twins are as large as 30°, and the variety is therefore near labradorite. It is quite fresh and the twinning lamellae abut sharply against the quartz grains.

A light colored, highly quartzose specimen shows abundant quartz, microcline, oligoclase, and a little biotite. The quartz is mostly in mosaics but many separate rounded grains lie entirely

within feldspar crystals. The plagioclase is fresh and the twinning lamellae end sharply against quartz grains. The apparently interstitial character of the feldspar, and the excessive amount of quartz are the only indications that this rock probably is a thoroughly recrystallized quartzite rather than a granite (Fig. 3).

The gneisses are intruded by granitic rocks. In places these have a sill relationship, and injection of the gneiss by granite *lit par lit* has taken place. It is difficult to estimate just how

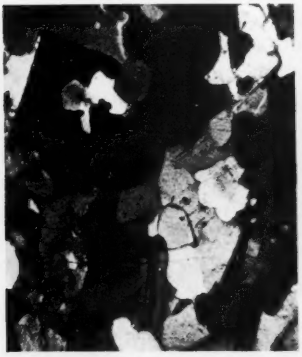

FIG. 2.

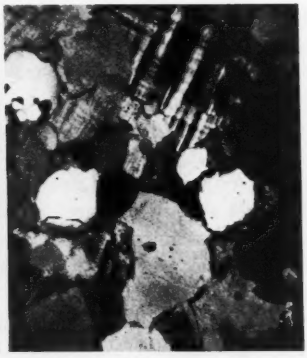

FIG. 3.

FIG. 2. Garnetiferous gneiss from drill core, Sherritt-Gordon mine. Crossed nicols. × 30. *G.* garnet; *B,* biotite; *F,* plagioclase; *Q,* quartz.

FIG. 3. Acidic gneiss from drill core. Crossed nicols. × 30. Mostly quartz and microcline.

great a part of the gneissic rocks may be igneous in character since the extreme metamorphism that they have undergone has produced recrystallization so thorough that many of them are decidedly like igneous rocks in texture. Those, however, which consist of abundant quartz associated with a feldspar near labradorite in composition are believed to have been rather calcareous sandstones. Most of the garnetiferous rocks are thought to be recrystallized sediments.

Structure of the Gneisses.—Along the southern margin of the typical gneisses the dip is fairly steep, varying along Kisseynew

Lake from vertical to dips of 75° northward. In a few places the dip is actually southward. Farther north the dip flattens so that at places along the shores of Kississing Lake the bands are essentially flat. Locally there are dips to the southward. Variations in strike of the beds produce troughs pitching northward. In a large way, the gneisses within the area seem to be the southern limb of a great syncline with an east-west axis lying somewhere to the northward. On this major structure are minor synclines and anticlines with east-west axes as well as cross folds, the axes of which pitch to the north. This complexity of structure is probably due to the intrusions of granite, which have disturbed the beds and destroyed the regularity of the simple structure produced by regional stresses. The minor folds depending upon the granite intrusions are important structural features economically, and will be discussed in greater detail later.

Age Relations.—The structure of the Kisseynew gneisses leaves no doubt that in this area at least the major part of them lies above the volcanics. It has been impossible, however, to find any definite break between the two series and the contact appears to be gradational. Rocks similar lithologically and probably continuous with the Kisseynew gneisses have been described by Alcock [3] at Wekusko Lake under the name of the Wekusko series. He found garnetiferous, staurolitic, and cyanitic biotite quartz gneisses interbedded with undoubtedly sedimentary quartzites which still retain the cross bedding of the original sands. Flows were found interbedded with the typical sedimentary gneisses.

So far as the age is concerned, it may be said that in the area under discussion, the sedimentary gneisses are younger than the volcanic rocks for the most part but there was no break between the formation of the two series and probably there was an interval of alternating volcanic and sedimentary deposition between the dominantly volcanic and the dominantly sedimentary periods.

Large bodies of granite of a normal character with typical coarse texture occur throughout the area. Marginally, and surrounding inclusions, there are lithological variations but over

[3] F. J. Alcock, Geol. Surv. of Canada, Mem. 119.

great areas the rock is a fresh bright pink, granite consisting of orthoclase and plagioclase, quartz, hornblende and biotite in varying proportions; magnetite, apatite and zircon occur in minor amounts; sericite and kaolin are in quantities depending upon the degree of alteration but seldom in more than very small amounts.

In the part of the area immediately south of Kississing Lake are various tongues and some fairly large masses of a fine-grained red granite that is distinctive enough to be mapped separately. The fine texture and red color are characteristic. Microscopically, this granite is found to contain orthoclase, microcline, quartz and biotite. The orthoclase shows some alteration but the rock is fairly fresh.

It is noteworthy that contacts of the fine-grained red granite with the gneisses are usually sharp. Ordinarily it has the structure of sills. In places it intrudes the gneisses *lit par lit* but there is practically no shatter zone, and it probably had little mineralizing effect.

THE ORE BODY.

Structure.—So far as present exploration has made it possible to picture the occurrence, the eastern part is decidedly lenticular, the western much more regular. The width of the regular western part varies from 8 to 10 feet normal to the walls. Some of the eastern lenses have a much greater thickness.

The strike of the vein is N.W. The dip varies. At the west end it is 30° N.E., flattening down the dip to a very low angle. Easterly along the vein, the dip steepens and at the east shaft the dip is steep to the southwest. Northeast of Shellet Lake the dip of the gneisses is to the south and there is probably a syncline in the sediments to the northeast of the western part of the vein. If so, there is the possibility that it will outcrop again to the northward but it is more likely that the anticline to the north of the small syncline has not been eroded deeply enough to expose it.

At most places the vein is conformable to the gneisses but there seem to be some offshoots of it which cross the structure. It was formerly thought that the ore lay between a hanging wall of basic gneiss and a footwall of acid gneiss. The relation is not so

simple. Either type of gneiss may be footwall or hanging wall.

Mineralogy.—The Sherritt Gordon ore is fairly coarse-grained. The metallic minerals present in it are pyrrhotite, chalcopyrite or chalmersite, sphalerite, and marcasite. The non-metallic minerals recognized are quartz, amphibole, possibly actinolite, chlorite, garnet, biotite and scapolite.

Pyrrhotite is by far the most abundant metallic mineral. The only noteworthy feature in it is the size of grain. Parting is well developed and some grains have much the appearance of a book of mica on account of this characteristic. A specimen recently sent to the writer by Mr. E. L. Brown, manager of the mine, shows parting planes nearly a quarter of an inch in diameter. The sphalerite and chalcopyrite are considerably less in quantity than the pyrrhotite. The average content of much of the ore is approximately 3 per cent. each of copper and zinc. The newer developments to the northwest and parts of the large lens at the 125 foot level of the east shaft carry somewhat greater quantities. The sphalerite is a purplish black variety and is of medium grain. Marcasite is present in the upper parts of the deposit but it is stated that none has been found far below the surface. Polished sections examined by Mr. G. D. Furse show a striking concentric or colloform structure. Of the metallic minerals, pyrrhotite is evidently the oldest as it shows replacement by the chalcopyrite and sphalerite. The sphalerite and chalcopyrite have a graphic structure, and it is impossible, so far as has yet been observed, to determine whether they are contemporaneous or of different periods. The marcasite is clearly later and probably represents reprecipitation of iron solutions just below the zone of weathering.

Quartz occurs quite abundantly in the ore. Most of it is in the form of rounded particles which, however, have rough surfaces as if they had been etched. None of them show crystal forms. Actinolite, in cigar shaped forms, is present and in places biotite is present. All of these are older than the sulphides and apparently were original constituents of the gneiss, the composition of which determined whether the ore should contain actinolite or

biotite. One well formed crystal of a dark gray scapolite was observed embedded in pyrrhotite. Chlorite is abundant along some of the ore margins.

A suite of specimens from a drill core which intersected the ore at a considerable depth below the surface shows the ore relations very clearly. In the hand specimen, the solid sulphides, which are chiefly pyrrhotite with some sphalerite, are separated from the gneiss by a zone from ⅛ to ¼ of an inch thick of a dull greenish mineral. A fracture extends outward from the

FIG. 4.

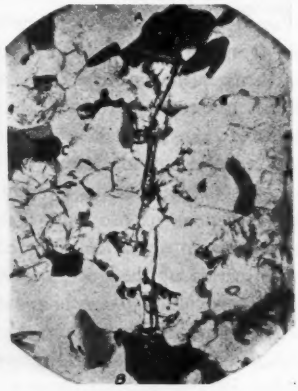

FIG. 5.

FIG. 4. From ore sample E shaft. × 10. Black—Chlorite and pyrrhotite. White—Quartz.

FIG. 5. From drill core. × 30. Black—Pyrrhotite. *A*, pyrrhotite surrounded by a ring of clorite in biotite (dark gray). *B*, pyrrhotite (black) lying between biotite and chlorite (zonal banding). *C*, pyrrhotite in biotite. No chloritic zone.

edge of this zone into the gneiss and this also is filled with the greenish mineral. A thin section of the green zone shows quartz which has been fractured and the fractures filled with chlorite (Fig. 4). Other areas which were apparently originally quartz are now so completely replaced that they have a mossy appearance. Foils of chlorite are abundant. These have the shape of the

biotite foils that occur in the biotitic beds of the gneiss. The sulphides replace the chlorite both of the mossy type and that which apparently is an alteration product from biotite. A thin section taken an inch from the border zone contains abundant quartz and biotite with some feldspar, both orthoclase and plagioclase. These have the closely interlocking mosaic texture of metamorphosed sediments. The biotite in places shows parts of a crystal chloritized and the other part still with the fresh brown color of the original mineral. Veinlets of chlorite intersect the quartz and feldspar, and in places there is evident the beginning of replacement of those minerals by tiny foils of chlorite working out from the veinlets. Pyrrhotite grains are abundant. Some of them replace biotite with no marginal zone (Fig. 5), but many of them are separated from the older minerals by a rim of chlorite. Some of these rims show a decided zonal structure. Some veinlets of chlorite occur joining two areas of chlorite which may or may not show grains of pyrrhotite in the central parts (Fig. 5). Other sections of ore exhibit the same phenomenon, a zone of light green to nearly colorless chlorite between the sulphides and the minerals of the gneiss. The color is paler as the distance from the sulphide grains increases.

Genesis of the Ore.—Any theory of origin of the deposit must explain its formation parallel to the bedding, the peculiar reversal in dip, *i.e.*, the warped plane of the deposit, the reason for the location in this area of heterogeneous acid and basic gneisses whereas other areas are barren, the presence of the large amount of quartz in the vein, the presence of garnet and scapolite, and the order observed in the deposition of the minerals. The general structure of the gneisses is that of a great syncline the southern limb of which dips away from the volcanics to the south. Along the main body of Kississing Lake the beds are at very low angles and there are many domes or minor anticlines and synclines that have their axes nearly transverse to that of the main fold. Along the east side of Kississing Lake, between that Lake and the Sherritt Gordon, the strike of the gneiss is N.W. and the dip to the N. E. As mentioned above, a minor syncline lies immediately

north of the mine. That is, the deposit lies on one limb of this minor fold.

The localization of the opening is probably due to the heterogeneity of the beds. It is well recognized that, where there is a marked difference in the competence of beds, folding will tend to cause movements parallel to the bedding and a resultant opening up of spaces along the axes of minor folds. The mechanism of the minor cross folds is not clear but it is possible that they are related to unexposed granite masses. An intrusion of greater size than ordinary with a thrust to the north may explain the reversal of the dip and the warping of the plane of the orebody, which is its most puzzling feature. It is suggested, therefore, that the opening or the weakness now occupied by the vein was formed because of the folding, the effects of which were especially great at this point on account of differences in the competency of the acid and basic gneisses. The cross folds may be the result of granite intrusions as yet unexposed and these are assumed also to explain the warped plane of the vein.

The rounded blebs of quartz distributed abundantly in the ore were evidently not original crystals since they could not have crystallized from any solution so basic as to have formed the sulphides. If there were an original quartzose zone largely replaced by sulphides the quartz would not be so evenly distributed as granules in the sulphides but would appear as more or less thoroughly replaced areas. If it be assumed that the quartz represents original quartz in a bed of sedimentary gneiss now largely replaced by sulphides, the arrangement, shape and etched character of the blebs is explained. The chlorite, mentioned above as a marginal facies of the ore zone, is evidently a product of the first stage of mineral deposition acting upon the enclosing rock. Original biotite was altered to chlorite, and the excess ferrous iron in the pyrrhotite mixture, uniting with the excess silica of the gneiss, formed the chlorite in the quartz grains and in the chlorite-filled veinlets. The scapolite and perhaps some of the garnet enclosed in sulphides, are further evidence of reaction between ore solutions and wall rock. All of the evidence points to

contact-metamorphic reactions between ore-bearing solutions high in iron upon the original minerals of a bed of gneiss along which had been localized shearing movements, due to disturbances perhaps the result of the invasion of the granite batholiths. These movements must have been most intense near upward-projecting masses of granite, and around these masses also ore solutions concentrated. There is thus a genetic relationship both structural and chemical between the granite and the orebodies. Evidently the ore must have been the result of the last stages of the granite cooling, since it occurs cutting the pegmatites which themselves are the products of late stages in the history of the igneous rocks.

Weathering.—Ordinarily, continental glaciation has removed the weathered material from rock surfaces in this region and the amount of weathering since glacial times has been insufficient to produce much gossan above the sulphide bodies. Locally, however, the geological structure has been such that weathered material, formed in the glacial times, has been preserved. It seems likely that the thick bed of rusty clays at Flin Flon has been protected from removal by the ridge of resistant greenstone to the northeast. Similarly, wherever the gneisses have a strike transverse to the glacial movement and especially where the dips are low to the north, any weathered products formed in any individual bed may be protected by an unweathered overlying stratum. At several places along the Sherritt Gordon vein, a considerable quantity of iron-stained material is found above the vein although in other places, notably where the vein comes to the lake at the original discovery pit, the unweathered sulphides are fairly close to the surface.

Along the extension of the vein beyond the west shaft sinkholes occur with ten to fifteen feet of the upper part of the vein completely removed and part of the space filled with till. Below the till is iron-stained material from which the sulphides have been weathered. At several places the weathering-out of the vein has allowed the hanging wall bed to cave in and completely mask the underlying sulphides and gossan, giving the impression

in the trenches that the vein does not occur in that part of the zone. In one place at least the persistence of the vein was demonstrated only by diamond drilling beneath the apparently barren surface.

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NEW OCCURRENCES OF GERMANIUM. II. THE OCCURRENCE OF GERMANIUM IN SILICATE MINERALS.[1]

JACOB PAPISH.

THE arc spectrographic method described in the preceding article of this series[2] was applied to a number of silicate minerals with the object of determining whether or not they were germaniferous. The observations were limited to the spectral range between λλ 2330 aand 3100 angstroms, and while there is a considerable number of germanium lines in this range, only λλ 2651.6, 2651.1 and, very frequently, 3039.1 were accounted for in the following tables. The reason for this will become apparent when one examines Table I. in the first article of this series.[3] These lines are the most persistent in the optical spectral range, *i.e.*, they are observed when the concentration of germanium is at its lowest in the zone of excitation, and they are sufficient to establish the presence of this element in a qualitative sense. In the tables, which are records of the observations, "v" is used to designate the fact that a line was plainly visible, "f" that it was faint, "vf." very faint, "a" absent and "d" doubtful. The last designation refers to a condition encountered when it is impossible to decide whether a line is exceedingly faint or totally absent. When a spectral line, especially one of great persistence, fades out because the quantity of excited vapor is diminished, it fades out not abruptly but very gradually. A stage is often reached when it is hard to distinguish an extremely faint line against a background of continuous spectrum, no matter how faint the latter is. The

[1] The investigation upon which this article (entitled by author "Germanium XXVIII") is based was supported by a grant from the Heckscher Foundation for the Advancement of Research, established by August Heckscher at Cornell University.

[2] ECON. GEOL., vol. 23, p. 660, 1928.

[3] *Idem*, p. 665.

spectroscopist is of course aware that whenever graphite rods are used as electrodes it is impossible to do away entirely with the continuous spectrum.

Topaz.—Thirty-one specimens of this mineral are listed in Table I. Three additional specimens of unknown origin were

TABLE I.

GERMANIUM LINES IN SPECTROGRAMS OF TOPAZ.

Topaz. No.	Place of Origin.	3039.1	2651.6	2651.1
1.	Tasmania	v	v	v
2[a]	Zinnwald, Bohemia	v	v	v
3[b]	Zinnwald, Bohemia	v	v	v
4.	Altenberg, Saxony	v	v	v
5.	Altenberg, Saxony	v	v	v
6.	Altenberg, Saxony	v	v	v
7.	Schlackenwald, Saxony		f	f
8.	Schneckenstein, Saxony	v	v	v
9.	Schneckenstein, Saxony		f	f
10.	Brodbo, Sweden	v	v	v
11.	Mursinsk, Siberia	v	v	v
12.	Sanark River, Ural		vf	vf
13.	Ural Mountains	v	v	v
14.	Tanakami, Yama Omi, Japan	f	f	f
15.	Naegi Mino, Japan	v	v	v
16.	Klein Spitzkopje, Southwest Africa	v	v	v
17.	New South Wales	v	v	v
18.	Silver Leaf Mine, Manitoba	v	v	v
19.	Nathpop, Chaffee Co., Colorado	v	v	v
20.	Florissant, Colorado	v	v	v
21.	Thomas Range, Millard Co., Utah	v	v	v
22.	Sevier Lake, Utah	v	v	v
23[c]	Trumbull, Conn.	v	v	v
24[d]	Trumbull, Conn.	v	v	v
25.	Easton, Conn.	v	v	v
26.	Monroe, Conn.	v	v	v
27.	Stoneham, Maine	v	v	v
28.	Stoneham, Maine	v	v	v
29.	Stoneham, Maine	v	v	v
30.	San Luis Potosi, Mexico	f	f	f
31.	Villa Rica, Brazil	v	v	v

a Variety, pycnite.
b Associated with cassiterite.
c Crystalline.
d Massive.

also examined. In all cases the spectrograms proved definitely that the minerals were germaniferous. With a number of specimens the lines due to germanium were both numerous and intense. This was especially true of specimens Nos. 1, 5, 6, 8, 10, 11, 13, 15, 16, 17, 18, 20, 22, 23, 24, 26, 27, 28, 29 and 31.

A weighed quantity of topaz from Silver Leaf Mine, Manitoba (No. 18), was decomposed by fusion with sodium carbonate, and the fused mass was subjected to distillation with hydrochloric acid. The distillate upon saturation with hydrogen sulphide yielded white germanium disulphide. The latter was removed by filtration and oxidized to the dioxide. The yield was low: 0.019 gm. of germanium dioxide was obtained from 18.3 gm. of topaz. A spectrographic examination of the residue in the distilling flask established the fact that a considerable quantity of germanium was retained by this residue. Efforts to extract the germanium from the residue by distillation with successive portions of hydrochloric acid were of no avail. This undoubtedly was due to the formation of that modification of germanium dioxide which is insoluble in hydrochloric acid.[4] While this experiment was a failure in a quantitative sense it served a purpose nevertheless: It made possible the extraction of some germanium from a new source.

TABLE II.

GERMANIUM LINES IN SPECTROGRAMS OF LEUCITE AND POLLUCITE.

No.	Mineral.	Place of Origin.	3039.1	2651.6	2651.1
1...	Leucite	Ariocia, Italy	vf	vf	vf
2...	Leucite	Vesuvius *	vf	vf	vf
3...	Leucite	Frascati, Rome, Italy	vf	vf	vf
4...	Leucite	Capo di Bovi, near Rome, Italy	a	a	a
5...	Leucite	Civita Castellana, Latium, Italy	a	a	a
6...	Leucite	Pompeii, Italy	vf	vf	vf
7...	Pollucite	Island of Elba	v	v	v
8...	Pollucite	Buckfield, Maine	f	f	f
9...	Pollucite	Black Hills, S. D.	v	v	v

* Eruption of February 10, 1847.

Leucite and Pollucite.—Six specimens of leucite and three of pollucite were examined. As seen from Table II. all the pollucites were germaniferous as well as some of the leucites. It should not be overlooked however that all the leucite specimens came from practically the same locality.

Mica.—In addition to the twenty-seven specimens of mica

[4] Müller and Blank, *Jour. Amer. Chem. Soc.*, 46, 2359, 1924.

listed in Table III. others were examined and found to be germaniferous. They are as follows: Coarse-grained lepidolite from Silver Leaf Mine, Manitoba, massive mica [5] and "rabenglimmer"

TABLE III.

GERMANIUM LINES IN SPECTROGRAMS OF MICA.

No.	Variety of Mica.	Place of Origin.	3039.1	2651.6	2651.1
1.	Lepidolite	Silver Leaf Mine, Manitoba	v	v	v
2.	Lepidolite	Paris, Maine	v	v	v
3.	Lepidolite	Mount Apatite, Auburn, Maine	v	v	v
3.	Lepidolite	Haddam Neck, Conn.	v	v	v
4.	Lepidolite	Middletown, Conn.	v	v	v
5.	Lepidolite	Peerless Mine, Keystone, S. D.	v	v	v
6.	Lepidolite	Ingersoll Mine, Black Hills, S.D.	v	v	v
7.	Lepidolite	Pala, California	v	v	v
8.	Lepidolite	Rozena, Moravia	v	v	v
9.	Lepidolite	Utö, Sweden	v	v	v
10.	Muscovite	Fillenberg, near Marienbad, Bohemia		d	d
11[a]	Muscovite	Mursinsk, Siberia	v	v	v
12[b]	Muscovite	Winter Harbor, Cumberland Sound		a	a
13[c]	Muscovite	Winter Harbor, Cumberland Sound			vf
14.	Muscovite	Speedway, New York City		a	a
15.	Muscovite	Paris, Maine	v	v	v
16.	Muscovite	Keene, New Hampshire	f	f	vf
17.	Muscovite	Chaffee County, Colo.		d	d
18.	Muscovite	Mitchell County, N. C.			vf
19.	Phlogopite	West Portland, Quebec			vf
20.	Biotite	Faraday Township, Ontario			vf
21.	Biotite	Mattawa, Ontario		d	d
22[d]	Biotite	Windham, Maine		a	a
23.	Fuchsite	Winnipeg River, Manitoba	v	v	v
24.	Fuchsite	Rutland, Vermont		a	a
25.	Fuchsite	Brunswick, Maine		f	f
26.	Fuchsite	Pfitsch, Tyrol		a	a
27.	Fuchsite	Zillerthal		f	f

a Associated with tourmaline No. 16. *c* Associated with feldspar No. 1.
b Associated with tourmaline No. 11. *d* Associated with kyanite No. 1.

from the same locality, "yellow lepidolite" from Keystone, South Dakota, and "yellow mica" [6] from Hybla, Ontario. It is safe

[5] "An exceedingly fine-grained, almost massive, mica, of a lilac-rose color, found occasionally associated with the normal lepidolite: the low lithia and high potash content of this mica indicate that it is near muscovite in composition." Spence, "Investigations of Mineral Resources and the Mining Industry," 1926, p. 15, Ottawa.

[6] This specimen was found upon spectroscopic examination to contain an appreciable quantity of barium. This was true to a lesser extent of the "yellow lepidolite" from Keystone, South Dakota.

TABLE IV.

GERMANIUM LINES IN SPECTROGRAMS OF FELDSPAR.

No.	Variety of Feldspar.	Place of Origin.	3039.1	2651.6	2651.1
1..	Orthoclase	Winter Harbor, Cumberland Sound	f	f	f
2..	Orthoclase	Fuchbach, Silesia	vf	vf	
3..	Orthoclase	Brevig, Norway	vf	vf	vf
4..	Orthoclase	Herschell, Ontario	f	f	vf
5..	Orthoclase	Jones Falls Quarry, Baltimore, Md.	f	f	f
6..	Orthoclase	Robinson, Colorado	f	f	f
7..	Orthoclase	Pikes Peak, Colorado	vf	vf	
8..	Orthoclase	Pacific Grove, California	f	f	f
9..	Microcline	Verona, Ontario	v	v	v
10..	Microcline	Bathurst, Ontario	v	v	v
11..	Microcline	Villeneuve, Quebec	f	f	vf
12..	Microcline	Bedford, New York	v	v	v
13..	Microcline[1]	Amelia Court House, Va.	v	v	v
14..	Microcline[1]	El Paso County, Colo.	f	f	f
15..	Microcline	Keystone, South Dakota	v	v	v
16..	Microcline[1]	Near Nain, Labrador	f	f	vf
17..	Albite	Alpe Ruschuna, near Vals, Switzerland	vf	vf	vf
18..	Albite[2]	Silver Leaf Mine, Manitoba	v	v	v
19..	Albite	Amelia Court House, Va.	v	v	v
20..	Albite [2]	Amelia Court House, Va.	f	f	f
21..	Albite	Keene, New Hampshire	v	v	v
22..	Albite	Norway, Maine	v	v	v
23..	Albite[2]	Keystone, S. D.	v	v	v
24..	Oligoclase	Siberia	v	v	v
25..	Oligoclase	Arendal, Norway	vf	vf	vf
26..	Oligoclase	Gilbertsville, Mass	f	f	vf
27..	Oligoclase	Orange County, N. Y.	f	f	f
28..	Oligoclase	Anthony's Nose, near Peekskill, N. Y.			vf
29..	Oligoclase	Media, Pa.	v	v	v
30..	Oligoclase	Virginia	vf	vf	vf
31..	Andesine	Cape Keglapait, Labrador		vf	vf
32..	Andesine	Bodenmais, Bavaria		d	d
33..	Andesine	Bodenmais, Bavaria		vf	vf
34..	Andesine	St. Raphael, France		f	f
35..	Andesine	Palmietfontein, Zoutpansberg, Transvaal		vf	vf
36..	Labradorite	Near Nain, Labrador	vf	vf	vf
37..	Labradorite	Near Sarnac Junction, N. Y.	d	d	d
38..	Labradorite	Aci Trezzo, Cyclopean Islands, Italy		a	a
39..	Labradorite	Mount Etna, Italy		d	d
40..	Labradorite	Millard County, Utah		d	d
41..	Bytownite	Bytown, Canada		vf	vf
42..	Bytownite	Crystal Bay, Minnesota	f	f	f
43..	Anorthite	Pesmed, Fassathal, Tyrol		vf	vf
44..	Anorthite	Mount Somma, Naples		f	f
45..	Anorthite	Miakejima, Japan		vf	vf

[1] Amazon stone.

[2] Cleavelandite.

to deduct from spectroscopic considerations that the lepidolites were consistently higher in germanium than the other micas.

Feldspar.—Spectrographic observations made on forty-five specimens of feldspar are recorded in Table IV. Judging from the number and intensity of the germanium spectral lines it may be concluded that the strictly alkali feldspars are richer in germanium than the others.

TABLE V.

GERMANIUM LINES IN SPECTROGRAMS OF TOURMALINE.

Tourmaline No.	Place of Origin	3039.1	2651.6	2651.1
1	Governeur, New York	vf	vf	vf
2	DeKalb, New York		vf	f
3	Haddam, Conn.	v	v	v
4	Dunderburg Mts., New York		f	f
5	Portland, Conn.		f	f
6	Gilson, New Hampshire	f	vf	f
7	Hebron, Maine	v	v	v
8[a]	Hebron, Maine	v	v	v
9	Rutheford, Maine	v	v	v
10	Chesterfield, Mass.	vf	vf	vf
11	Winter Harbor, Cumberland Sound		f	f
12[a]	Pala, California	v	v	v
13	Prevali, Carinthia			vf
14	Brevig, Norway	v	v	v
15[b]	Livinerthal, Switzerland		d	d
16	Mursinsk, Siberia	v	v	v
17	Island of Elba	v	v	v
18	Anjanabonoina, Madagascar	v	v	v
19[a]	Minas Geraes, Brazil	v	v	v
20.[a]	Wolkenburg, Saxony		vf	vf
21[a]	Utö Mines, Södermondland, Sweden	v	v	v

a Variety, rubellite. *b* Associated with dolomite.

Tourmaline.—Twenty-one tourmalines were examined spectrographically for the presence of germanium. As seen from Table V. one specimen (No. 15) gave doubtful results while the remaining ones were found to be germaniferous.

Andalusite.—Seven specimens of this mineral from as many different localities were subjected to spectrographic analysis, and it was observed that they were all germaniferous. The results are recorded in Table VI.

Kyanite.—In Table VII. are recorded the results of the analysis

TABLE VI.

GERMANIUM LINES IN SPECTROGRAMS OF ANDALUSITE.

Andalusite No.	Place of Origin.	3039.1	2651.6	2651.1
1	Neualbenreuth, Bavaria	f	f	f
2	Lisenvalley, Tyrol	v	v	v
3	Fillenberg, near Marienbad, Bohemia	v	v	v
4	Leiperville, Pa	f	vf	f
5	Lancaster, Mass		vf	vf
6	Westford, Mass	f	vf	f
7	White Mountains, N. H	v	v	v

of five specimens of this mineral. It will be noticed that all the kyanites were germaniferous.

TABLE VII.

GERMANIUM LINES IN SPECTROGRAMS OF KYANITE.

Kyanite No.	Place of Origin.	3039.1	2651.6	2651.1
1	Windham, Maine	v	v	v
2	Newtown, Conn	v	v	v
3	Blandford, Mass	v	v	v
4	Moores, Pa	v	v	v
5	Chester County, Pa	f	f	f

Sillimanite.—Four specimens of sillimanite were examined spectrographically and only one of them gave a definite indication that it was germaniferous. The germanium spectral lines, being

TABLE VIII.

GERMANIUM LINES IN SPECTROGRAMS OF SILLIMANITE.

Sillimanite No.	Place of Origin.	3039.1	2651.6	2651.1
1	Norwich, Conn	d		d
2	Chester, Conn	d		d
3	Custer, South Dakota	d		d
4	Brandywine Springs, Delaware	f	f	f

few in number and faint, point to a very low content of this element.

Pyroxene.—In Table IX. are recorded the results obtained

from the examination of the spectra of twenty-four different pyroxenes. In addition to these, two specimens of hypersthene and two of bronzite were examined and in all four cases it was impossible to arrive at definite conclusions regarding the presence of germanium because of spectral line interferences.

TABLE IX.

GERMANIUM LINES IN SPECTROGRAMS OF PYROXENE.

No.	Variety of Pyroxene.	Place of Origin.	3039.1	2651.6	2651.1
1..	Spodumene	Halstead, New Hampshire	v	v	v
2..	Spodumene	Goshen, Mass.	vf	vf	vf
3..	Spodumene	Norwich, Mass.	v	v	v
4..	Spodumene	Chesterfield, Mass.	f	f	f
5..	Spodumene	Auburn, Maine	v	v	v
6..	Spodumene	Andover, Maine	v	v	v
7..	Spodumene	Oxford Co., Maine	v	v	v
8..	Spodumene	near Paris, Maine	v	v	v
9..	Spodumene	Cahuilla, California	v	v	v
10..	Spodumene	Minas Geraes, Brazil	v	v	v
11..	Spodumene	Utö, Sweden	v	v	v
12..	Kunzite[1]	Pala, California	v	v	v
13..	Kunzite[2]	Pala, California	v	v	v
14..	Kunzite[3]	Pala, California		f	f
15..	Kunzite[4]	Pala, California	v	v	v
16..	Hiddenite	Hiddenite, Alexander Co., N. C.		vf	vf
17..	Diopside	DeKalb, New York	vf	vf	vf
18..	Diopside	Patterson, N. J.	vf	vf	vf
19..	Diopside	Haliburton County, Ontario		a	a
20..	Enstatite	Pelham, Mass.		d	d
21..	Wollastonite	Natural Bridge, N. Y.		a	a
22..	Wollastonite	Orange County, N. Y.		d	d
23..	Augite	Buffaura, Fassathal, Piedmont		vf	vf
24..	Augite	Fassathal, Piedmont		a	a

[1] Intense pink. [3] Colorless.
[2] Pale pink. [4] Pale blue.

Amphibole.—Of the thirteen amphiboles examined (see Table X.) only one specimen of actinolite and one of tremolite were found to be germaniferous to a very slight extent, a conclusion based on the fact that the germanium spectral lines were few and faint.

Cordierite.—A specimen of this mineral from Cape Keglapait, Labrador, which was associated with the andesine from the same locality listed in Table IV., was examined, and its spectrograms

were found to show very faintly the germanium lines λλ 2651.6 and 2651.1.

Hornblende.—Specimens of hornblende from several different localities were subjected to spectrographic examination. Because of spectral line interferences it is deemed preferable not to draw conclusions regarding the presence of germanium in hornblende.

TABLE X.

GERMANIUM LINES IN SPECTROGRAMS OF AMPHIBOLE.

No.	Variety of Amphibole.	Place of Origin.	3039.1	2651.6	2651.1
1..	Actinolite	Mineral Hill, Pa.	f	f	vf
2..	Actinolite	Brewsters, New York		a	a
3..	Actinolite	Kent, Putnam County, N. Y.		a	a
4..	Tremolite	Amity, Orange County, N. Y.	vf		vf
5..	Tremolite	Canaan, Conn.		d	d
6..	Tremolite	Ossining, New York		d	d
7..	Anthophyllite	Copper Mine, Washington County, Md.		d	d
8..	Anthophyllite	Kipps Bay, New York City		a	a
9..	Anthophyllite	Harford County, Md.		d	d
10..	Mountain leather	Nova Scotia		a	a
11..	Asbestos	Germany		d	d
12..	Asbestos	Thetford, Quebec		d	d
13..	Riebeckit	St. Peter's Dome, El Paso Co., Colo.		d	d

Talc.—Two specimens of this mineral, one from Rochester, New Hampshire, and the other from Fengtien, Manchuria, were examined spectrographically. The spectrograms in each case did not contain lines due to germanium.

Chlorite.—Clinochlor from West Chester, Pennsylvania, and clintonite from Amity, New York, gave negative results when their spectrograms were examined for the presence of germanium lines.

Serpentine.—What was said of talc and chlorite in connection with germanium spectral lines will also apply to a specimen of serpentine from Lynfield, Massachusetts: These lines were absent.

Quartz.—Many of the silicate minerals listed in the preceding tables were associated with quartz, and accordingly it was decided to examine this substance for the presence of germanium. In the periodic table of the chemical elements germanium occupies the

position between silicon and tin and in its chemical behavior it resembles strikingly these two congeners. Were it not for the solubility of germanium dioxide in water [7] there would be ample justification to regard this substance as a replacement product of silicon dioxide, at least in part. A glance at Table XI., which is a record of the examination of five quartz samples, will disclose the fact that germanium lines were not present in the spectrograms obtained. The same was true of two specimens of opal, one from Virgin Valley, Humboldt County, Nevada, and the other from Mexico.

TABLE XI.

GERMANIUM LINES IN SPECTROGRAMS OF QUARTZ.

No.	Variety of Quartz.	Place of Origin.	2651.6	2651.1
1[a]	Vein quartz	Silver Leaf Mine, Manitoba	a	a
2[b]	Vein quartz	Rutheford, Maine	a	a
3[c]	Vein quartz	Keystone, South Dakota	a	a
4.	Smoky quartz	Uri, Switzerland	a	a
5.	Chalcedony	Unknown	a	a

a Associated with lepidolite (Mica No. 1, Table III.).
b Associated with tourmaline No. 9, Table V.
c Associated with albite (Feldspar No. 23, Table IV.).

SUMMARY AND CONCLUSIONS.

The presence of germanium has been observed in certain specimens of the following silicate minerals: Topaz, leucite, pollucite, lepidolite, muscovite, phlogopite, biotite, fuchsite, orthoclase, microcline, albite, aligoclase, andesine, labradorite, bytownite, anorthite, tourmaline, andalusite, kyanite, sillimanite, spodumene, kunzite, hiddenite, diopside, augite, actinolite, tremolite and cordierite.

Barring some specimens of topaz, lepidolite, tourmaline and spodumene, it is safe to conclude that the germanium content of the minerals examined is very low. The few faint spectral lines of germanium point to the presence of traces of this element.

[7] One part of germanium dioxide dissolves in 247.1 parts of water at 20° and in 95.3 parts of water at 100°. Winkler, *Jour. f. prak. Chemie*, 142, 212, 1886.

The detection of germanium in feldspars from different localities is significant in establishing the fact that this element is of wide distribution.

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NOTES ON ETCHING TESTS AND X-RAY EXAMINATION OF SOME MANGANESE MINERALS.[1]

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THE following article represents the laboratory study undertaken in connection with the field investigation of manganese occurrences in the Maritime Provinces, Canada.[2] Complementary to the main text of this paper there is added a short review of a number of hausmannite occurrences; also there is included a summary of the mineralogy and occurrence of the maritime deposits and suggestions as to the possible mode of transportation and deposition of the manganese in these deposits.

MICROCHEMICAL ANALYSIS.

The minerals that were examined critically include manganite, pyrolusite, hausmannite, braunite, and bementite; psilomelane and wad were also investigated, but due to the nature of these minerals the results may be ambiguous if compared with those obtained from specimens selected from other localities.

In determining the etching reactions the reagents used by Thiel[3] were employed. The ones found to be most applicable were:

(1) Hydrochloric acid (HCl) N/6 and concentrated.
(2) Sulphuric acid (H_2SO_4) concentrated.
(3) Hydrogen peroxide (H_2O_2) 30 per cent. Ordinary commercial H_2O_2 gave no reactions except with pyrolusite.
(4) Stannous chloride ($SnCl_2$) dilute and concentrated.
(5) Ferrous chloride ($FeCl_2$) concentrated.

Type specimens, well-crystallized, of the different minerals were chosen from the Museum Collection. These were carefully

[1] Printed by permission of the Director of the Geological Survey of Canada.

[2] Doctorate thesis, Massachusetts Institute of Technology, 1928.

[3] G. A. Thiel, The Manganese Minerals: Their Identification and Paragenesis. ECON. GEOL., 19, pp. 107–145, 1924.

polished, and then the reactions on them, due to the above named reagents, were noted, and these results were used as a basis for the examination of the ores collected by the writer during his field work.

In polishing, the best results were obtained by first grinding the specimens until they were ready for finishing with fine optical alundum, followed by chromium oxide, or rouge. At this stage the specimens were impregnated with bakelite and then dried thoroughly. After this the final fine grinding and polishing were completed. A well-polished surface is necessary to obtain uniform results; if the surface is poorly polished with scratches and pits prominent anomalous results will be obtained even with the same specimen.

In checking through the ores collected in the field it was observed that where two oxides were intimately associated, or finely intergrown with one another—usually pyrolusite forming as an alteration product—the etching tests became somewhat unsatisfactory and tended to assume the characteristics of the more active (towards reagents used) mineral, provided this was present in fair amount. This discrepancy is most pronounced with an intergrowth of manganite and pyrolusite. However, where the minerals are well-crystallized and are not intimately intergrown—as can easily be determined by the color contrast on a well polished surface—the etching tests, so far as could be determined, appeared to give reliable results.

Manganite.—The specimen chosen as typical of manganite came from Ilfeld, Harz, Germany. This specimen consists of numerous prismatic crystals, up to one centimeter in length, and 2 to 3 millimeters in cross section, set upon a mass of small interlocking prismatic and platy crystals. The prismatic faces of the crystals are well striated, parallel to the elongation. The basal pinacoids exhibit series of fine striations parallel to the longer diameter (b axis crystallographic) suggestive of multiple twinning but etching failed to develop any such structure. Examination under the reflecting microscope showed that the basal pinacoid of any one of these large crystals is not a homogeneous

surface; instead many minute diamond-shaped outlines could be distinguished. This suggested that the large crystals are not single individuals but rather composite masses of many small acicular crystals in parallel growth. Laue photographs of the specimen bear this out.

The chemical analysis [4] of the specimen is:

		Corrected.	*Recalculated.*[5]
Fe_2O_3	.15	.150	
MnO	80.50	80.575	80.694
O	9.06	9.068	9.082
H_2O	10.20	10.207	10.224
	99.91	100.000	100.000

The results of the etching tests are given below:

Color—steel gray.

Hardness—medium.

Streak—brown. Shades of brown by transmitted light.

HCl (dil.)—drop slowly turns pale green. Prolonged reaction may produce a very slightly darker shade of gray after washing specimen.

HCl (conc.)—drop turns green and as reaction proceeds assumes a yellow to brown cast. This color change takes place first along grain boundaries, scratches, and cracks. Washed to a surface on which the scratches are slightly emphasized, and that is a slightly darker shade of gray than the original.

H_2SO_4 (conc.)—negative.

H_2O_2—30 per cent. very slight effervescence.

Surface washes to a slightly darker gray.

$SnCl_2$ (dil.)—on face 1.00. Slowly etches under drop to a darker surface. Washes to a dark dirty gray surface which shows the development of scratches. On face 010. Slow etching under drop. Washes to a surface showing scratches emphasized but only slightly darker than original. Drop appears to have eaten into mineral without destroying polish. On face 001. Similar to 100 but less pronounced. 100 darkens very quickly and washes to a very dark gray surface. If action is not allowed to go too far it will be seen that areas between scratches retain their polish. The dark

[4] F. A. Gonyer, Washington, D. C., analyst.

[5] Considering Fe_2O_3 as impurity of hematite. Theoretical percentage of MnO in manganite = 80.668.

shade of gray due to innumerable exceedingly fine scratches that are developed along with the coarse scratches. This holds for other sections too.

$SnCl_2$ (conc.)—010. Drop eats into crystal with little or no etching Surface retains polish and is only slightly darker than original. Effect more pronounced than with dil $SnCl_2$.

001. Similar to 100. Cracks and scratches develop. Cracks suggest the cleavage 010 but this is not definite.

$FeCl_2$—Same as $SnCl_2$ but less pronounced.

In the ores examined the above effects were slightly more pronounced. The hardness varies from medium to hard and the streak from yellowish brown to dark brown.

Thiel's results are: "Color grayish white. $SnCl_2$—a few seconds after application the needle-like grains of mineral are brought out. Extended action produces a dark surface deeply etched with an irregular pattern. H_2SO_4 fumes tarnish slightly. Rubs to a brown surface. H_2O_2 (commercial)—slightly effervescent if allowed to act a minute or more. Tarnishes to a darker gray, especially with $H_2O_2 + H_2SO_4$. $AuCl_3$—neg."

Pyrolusite.—Type specimen from New Brunswick; locality not listed. This is soft, well-crystallized ore with the pyrolusite in platy crystals. Analysis [6] of the pyrolusite gave:

		Corrected.
SiO_2	.88	.879
Fe_2O_3	.64	.639
Al_2O_3	.08	.08
CaO	2.40	2.397
MgO	.60	.599
MnO	77.94	77.831
O	16.40	16.377
H_2O	1.20	1.198
	100.14	100.00

Etching tests:

Polished surface shows an aggregate of needle-like crystals and platy forms showing marked cleavage (or parting) parallel to sides. Needles showed cleavage (or parting) normal to and at angles to long axis.

Color—cream white.

Hardness—quite soft.

Streak—black. Opaque to transmitted light.

[6] F. A. Gonyer, Washington, D. C., analyst.

HCl (dil.)—drop slowly turns green to greenish brown and gradually darkens in brown shade. Washes clean. No etching.

HCl (conc.)—immediately turns greenish brown and then darkens to brown rather quickly. Washes clean with slight development of scratches and slight darkening of surface.

H_2SO_4 (conc.)—apparently no effect. After some time a very slight effect may take place. No etching. Washes clean. No darkening.

H_2O_2—30 per cent. Violent effervescence. After reaction has proceeded for some time specimen washes clean and shows a slightly darkened surface under drop.

$SnCl_2$ (dil.)—very slowly etches and brings out scratches and grain boundaries. Washes to a brown surface under drop.

$SnCl_2$ (conc.)—immediately etches black. Produces excessive etching. Washes and rubs to black deeply etched surface.

$FeCl_2$—similar to $SnCl_2$ but less pronounced.

The hardness of the pyrolusite in the ores varies from soft to medium and in one or two instances to hard. Whether the hard varieties corresponded to polianite is not known as chemical analysis was not possible.

In the ores, especially the fine-grained soft varieties, the reactions correspond, but in the harder ores the reactions become modified and approach those of manganite. However, H_2O_2 and SnCl (conc.) always produce decided reactions.

Associated with some of the pyrolusite there is a mineral that, on polished surface, is slightly harder than the pyrolusite and polishes to a white surface. The microchemical reactions of this mineral are exactly the same as those of pyrolusite.

Thiel's results are: "Color brownish white. $SnCl_2$ fumes tarnish brown. Solution becomes dark. Rubs to a deeply etched pitted black surface. H_2O_2 effervesces profusely. H_2O_2 + H_2SO_4 effervesces with etching. $AuCl_3$ plates in 48 hours. Specimens with a hardness of 3 are partially covered with minute grains of gold on polished surface."

Hausmannite.—The specimen used as typical of this mineral came from the occurrence on McVicar's farm, Cape Breton Island. It is a crystalline massive ore with which are associated calcite and rhodochrosite. Where the carbonate has been leached, small simple and twinned tetragonal pyramids are exposed.

The mineral polishes to a smooth surface. Under the microscope the majority of grains are smooth, but a considerable number show various shades of gray, and close examination reveals this to be due to innumerable fine flaws on the surface. The regularity of arrangement of these pits suggests either an intimate intergrowth of two minerals, or a fine chipping of the surface along a crystal direction during the polishing. This latter hypothesis is favored by the writer. The results of observations on the above specimen were checked against hausmannite from Långban, Sweden, and were found to coincide. The same variations in color from white to various shades of gray are to be noted in the Långban ore, and these variations are associated with those grains that exhibit twinning.

Analysis [7] of the specimen from Cape Breton gives:

		Corrected.	Recalculated.[8]
Fe_2O_3	.04	.04	
MnO	92.72	92.925	93.055
O	6.92	6.935	6.945
H_2O	.10	.100	
	99.78	100.000	100.000

The best analyses [9] listed from different occurrences are given in the following table. Other analyses given show the MnO content to range from 83.4 per cent. to 86.5 per cent.

The etching reactions are:

Color—appears white when a uniform field is seen but in contrast to replacing pyrolusite it shows up as a light gray with a bluish cast.

Hardness—hard.

Streak—rich chestnut brown. Deep cherry red by transmitted light.

HCl (dil.)—drop slowly turns a pale green and then darkens around edges in shades of yellowish brown. Washes clean, surface remains bright.

HCl (conc.)—drop quickly turns green about periphery and then darkens

[7] F. A. Gonyer, *op. cit.*

[8] $Fe_2O_3 + H_2O$ impurities as limonite and water. Theoretical amount of MnO in hausmannite = 93.015 per cent.

[9] C. Doelter, "Handbuch der Mineralchemie," 1926.

TABLE I.

	a	*b*	*c*	*d*	*e*
Alkaline			0.45		
O	7.10	6.95	6.54	7.78	8.87
MgO		0.41	0.30	trace	
CaO		0.14	0.44	trace	
MnO	92.48	92.12	87.34	91.38	90.40
ZnO			0.70		
BaO	0.14	0.13	0.07	0.26	
PbO			—		
Fe_2O_3			3.47		
CO_2			0.19		
SO_3			—		
P_2O_5			—		
H_2O		0.34	—	0.62	1.03
SiO_2	0.17				0.10
Gang			0.90		
Iron and alumina					0.48
	99.89	100.09	100.40	100.04	100.88

(*a*) Ilmenau, pure crystal.

(*b*) Filipstad, Wermland, Sweden, crystal in limestone.

(*c*) Långban, part crystal, part dense.

(*d*) (*e*) Batesville, Arkansas, U. S. A. H. D. Miser and J. G. Fairchild, Washington Academy Science Journal, 1920, pp. 1–8.

in shades of yellow and brown; more pronounced than with dilute HCl. If drop left for some 1 to 2 minutes, and then washed, surface is etched to a very light brown with development of fine scratches. Otherwise washes clean with slight development of scratches.

H_2SO_4 (conc.)—neg.

H_2O_2 30 per cent.—very slight effervescence. No tarnishing.

$H_2O_2 + H_2SO_4$—quickly effervesces and after reaction has proceeded for 1 to 2 minutes, if washed, surface shows a slight tarnishing to light brown and the development of small irregularly rounded bodies along cracks, scratches, etc. This is due to a precipitation, as a crack may be observed to pass under several such bodies and continue between and on either side of the precipitate.

$SnCl_2$ (dil.)—same as $SnCl_2$ (conc.) but less pronounced and slower reactions.

$SnCl_2$ (conc.)—quickly etches with development of scratches. Washes and rubs to a gray-brown scratched surface. Grain boundaries and cracks developed. If action proceeds for 1 or 2 minutes iridescent surface obtained.

$FeCl_2$—same as $SnCl_2$ but slightly less pronounced.

Thiel's results: "Color gray white. $SnCl_2$ fumes tarnish with iridescence. Surface brown, rubs to coarse reticulate etched pattern. Many grains have appearance of lattice work. Cleavage brought out. H_2O_2—very slight effervescence. No tarnish. $AuCl_3$—neg. on fresh surface. Plated on surface of amorphous material produced by roasting psilomelane."

Braunite.—Type specimen came from Långban, Sweden, and is well crystallized. In the ores examined the braunite occurred as fine dense masses, but is always well crystallized in small prisms with pyramidal terminations.

Etching tests give:

Color—white when by itself. In association with pyrolusite appears light gray with blue tinge.
Hardness—very hard.
Streak—black or a brownish black. Powder slightly magnetic.
HCl (dil. and conc.)—neg. H_2SO_4 (conc.) neg. H_2O_2, 30 per cent—slight effervescence, along cracks. $H_2SO_4 + H_2O_2$—very slight effervescence. No tarnish.
$SnCl_2$ (dil.)—very slight, almost negative reaction after long time of reaction. Effects are similar to conc. $SnCl_2$ but less pronounced.
$SnCl_2$ (conc.)—etches to a brownish gray surface with slight development of scratches and grain boundaries.
$FeCl_2$—similar to $SnCl_2$.

Thiel's results: "Color light grayish white. $SnCl_2$—turns grayish brown; rubs to a very slightly etched surface. H_2O_2—effervesces very slowly and that is confined to fractures. $AuCl_3$—negative on fresh surface. Negative on same surface following roast."

Bementite.—The specimen of bementite examined was submitted through the courtesy of J. T. Pardee, and was collected by him in 1918 from the Apex claim, north fork of Skakomish River, Washington. It is a mottled rock, varying in color from a light greenish gray to various shades of brown; the slickensided faces are a dark ruby red; and veinlets and specks of calcite are common. The specimen does not appear to be a uniform mineral. Microscopic examination reveals a mineral with indices 1.625 + and 1.650 +, these agreeing with the α and γ of the bementite

from the Trotter Mine, Franklin Furnace.[10] This mineral in the specimen from Washington is a very fine-grained aggregate and it was not possible to obtain further optical data on it.

A powder photograph was made of a fine powdered sample of this specimen and is included in Fig. 1. The writer thinks this should be accepted with reserve as representing a powder photograph of pure bementite.

Psilomelane.—The specimen examined as representing psilomelane came from Crimora, Virginia, and is a dense ore showing concentric layers of varying shades of black; here and there minute veinlets and specks of crystalline ore (pyrolusite) may be seen in the specimen. A polished surface emphasizes the concentric structure. Under the reflecting microscope the main groundmass is composed of concentric layers of a gray-brown dense material of hardness about 4.5. Ramifying through this is a mineral that polishes to a white color and is harder than the matrix. This evidently represents a secondary change within the ore after its deposition.

The etching tests obtained on the smoothly polished white mineral are:

HCl (dil.)—etches and washes to a gray scratched surface.

HCl (conc.)—same reaction as dil.HCl, but more pronounced and quicker. More pronounced in surrounding material, in both cases.

H_2SO_4 (conc.)—slowly darkens under drop and washes and rubs to a grayish to brown surface.

H_2O_2 30 per cent.—slight and slow effervescence. After reaction has proceeded for about 1 minute, washes to a slightly darker shade. Surrounding material effervesces freely and darkens.

$H_2O_2 + H_2SO_4$—effervesces and darkens, washes and rubs to a dirty gray surface. Surrounding material etches black.

$SnCl_2$ (dil.)—neg.

$SnCl_2$ (conc.)—immediately blackens and etches deeply.

$FeCl_2$—same as $SnCl_2$—somewhat less pronounced. Effect on surrounding material, more intense in both cases.

Thiel's results: "Color, light gray-white. $SnCl_2$—tarnishes with etching, rubs to a gray finely textured etched figure. H_2SO_4—

[10] E. S. Larsen, "Microscopic Examination of Non-opaque Minerals," U. S. Geol. Surv. Bull. 672, p. 46, 1921.

tarnishes brown, rubs to a pale brown with slight etching. H_2O_2—effervesces profusely, rubs clean. $AuCl_3$—no plating on freshly polished surface, but with electric roast to 950° followed by $AuCl_3$, a film of metallic gold and manganese oxide is deposited."

Wad.—The specimen of wad examined came from the occurrence on Mr. Hebb's farm, Conquerall, Nova Scotia. The polished section shows a very intimate intergrowth of two minerals; one is white and the other is a pale blue to light gray-blue. The etching reactions obtained on these two are:

Hardness—both quite soft.

HCl (dil.)—blue mineral darkens more quickly than white but on washing and rubbing, white is more deeply etched. Action quick.

HCl (conc.)—same relative action but results more pronounced.

H_2SO_4 (conc.)—minerals slowly darken under drop; on washing and rubbing grayish blue mineral appears to be more deeply etched; white also etched and darkened.

H_2O_2 30 per cent.—effervescence starts on gray-blue mineral and then over whole drop, concealing reaction on minerals. Washes and rubs to darker surface on both minerals.

$SnCl_2$ (dil.)—gray-blue mineral darkens quickly, white stands out, washing quickly and rubbing shows gray-blue mineral to be etched almost to a black, while white mineral is darkened, but little or no etching.

$SnCl_2$ (conc.)—both darken immediately. On washing and rubbing white mineral is less deeply etched than the other.

From the observations made during the above reactions the writer suspects the presence of more minerals than mentioned but the color contrast is too small and the intergrowth too delicate to allow of distinction.

X-RAY ANALYSIS.

Discussion of Results.—X-ray spectographs of the type specimens were obtained by the powder method. The specimens were finely ground and then mounted on hairs. The results obtained were definite and quite characteristic of the different minerals. Powder photographs of the specimens used are plotted in Fig. 1. The height of a line represents the intensity of that line on the film. The horizontal distance is plotted on a logarithmic scale and the distance, as measured on the scale gives, in Ångstrom units (10^{-8} cm.), the spacing of the atomic planes in the mineral.

Films 1, 4, 5, 6, 7, 8 and 13 represent the type specimens of manganite, pyrolusite, psilomelane, hausmannite (Cape Breton), bementite, braunite, and wad, respectively. The other films were made as checks against various specimens of ore collected by the

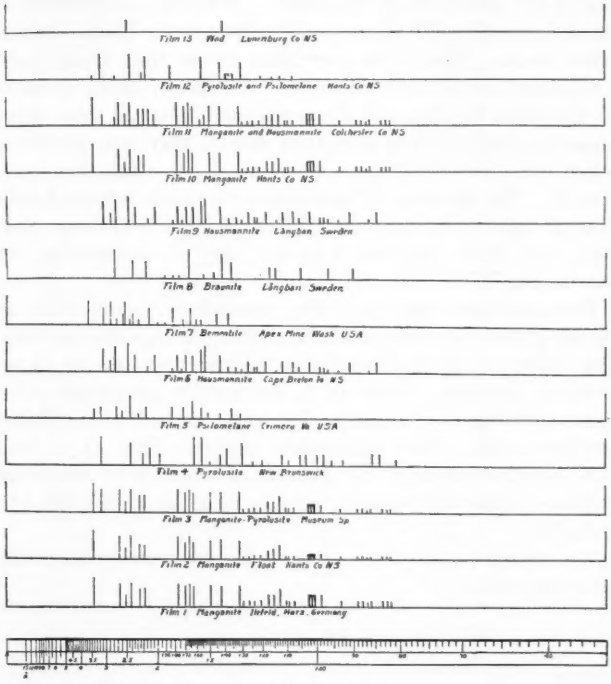
Film 13 Wad Lunenburg Co N S
Film 12 Pyrolusite and Psilomelane Hants Co N S
Film 11 Manganite and Hausmannite Colchester Co N S
Film 10 Manganite Hants Co N S
Film 9 Hausmannite Långban Sweden
Film 8 Braunite Långban Sweden
Film 7 Bementite Apex Mine Wash U S A
Film 6 Hausmannite Cape Breton Co N S
Film 5 Psilomelane Crimora Va U S A
Film 4 Pyrolusite New Brunswick
Film 3 Manganite-Pyrolusite Museum Sp.
Film 2 Manganite Float Hants Co N S
Film 1 Manganite Ilefeld, Harz, Germany

FIG. 1.

writer, the minerals of which were first determined by etching tests.

Film 2 represents the specimen of manganite float found by Mr. L. Reynolds, about five miles south of the Faulkner mine. Film 3 was made as a check on a museum specimen marked pyrolusite, but determined by etching tests to be predominantly manganite with a small amount of pyrolusite forming as an alteration product.

The second line on this film corresponds to the first pyrolusite line; the remaining ones being either too faint to show, or else covered up by the manganite lines. Film 8 is hausmannite from Långban, Sweden. The lines on the film are streaked and coarse, due to the powder being too coarse. Film 10 is a specimen of dense hard manganite from the Stephen's mine, Hants County, Nova Scotia. Film 11 is a specimen of ore from Black Rock, Colchester County, Nova Scotia. This specimen shows remnants of colloform banding and the crystallized minerals were determined microscopically as manganite, mainly, altering to pyrolusite which is in subordinate amount and usually as a very fine intergrowth. The presence of hausmannite was not suspected until after a study of the film, and on this the lines at spacings 3.07, 2.74, 2.11, 2.03, 1.57 and 1.53 are taken as representing the hausmannite lines.

Re-examination microscopically revealed the hausmannite as minute grains and clusters here and there through the specimen. The relation of the hausmannite to the manganite can not be determined definitely. Film 12 is the powder photograph of a specimen of hard ore from the Tennycape estuary and is mainly pyrolusite with a little psilomelane present. Film 13 of wad bears out the statement that there is no evidence of crystalline structure in the wad, showing it to be made up of colloidal (?) particles.

The measurements of the lines on the films are given in the following table:

TABLE II.

MEASUREMENTS OF POWDER PHOTOGRAPH FILMS.*

Manganite

3.4	h	1.210	e.w.
2.65	m	1.177	v.w.
2.52	v.w.	1.155	v.w.
2.41	m	1.13	w
2.26	w	1.113	e.w.
2.18	w	1.095	e.w.

* h = heavy, m = medium, w = weak, v.w. = very weak, e.w. = exceedingly weak.

1.77 m	1.076 e.w.
1.70 w +	1.027–1.007 v.w.
1.665 m	wide blur
1.63 w +	
1.495 m —	0.987 v.w.
1.425 m —	0.932 e.w.
1.317 m —	0.89 e.w.
1.292 e.w.	0.878 e.w.
1.263 e.w.	0.867 e.w.
1.24 e.w.	0.86 e.w.
	0.835 e.w.
	0.826 e.w.
	0.819 e.w.

Films 1, 2, 10.

Films 3, same as 1, with line at 3.13.

Film 11, same as 1, with lines at

Hausmannite lines { 3.07 v.w. / 2.74 e.w. / 2.11 w. / 2.03 v.w. / 1.57 e.w. / 1.53 v.w.

Pyrolusite

3.12 h	1.20 ?
2.41 m	1.12 v.w.
2.20 v.w. +	1.09 e.w.
2.10 w	1.052 v.w.
1.970 v.w.	1.032 v.w.
1.620 h	
1.555 h	0.998 v.w.
1.50 ?	0.979 v.w.
1.435 v.w.	0.955 v.w.
1.385 w	0.926 e.w.
1.30	0.857 v.w.
1.245 ?	0.84 v.w.
	0.807 e.w.

Film 4.

Film 12, mostly pyrolusite with psilomelane lines at 2.73
2.15
1.83

Measurements of Film 12—

3.11	m—
2.73	e.w.
2.39 +	m +
2.21	e.w.
2.15	m

1.98 e.w.?
1.83 w
1.55 m—
1.42 w
1.387–134 wide band e.w.
1.30 w
1.20, 1.155, 1.121, 1.075 ?

Psilomelane

3.35 v.w.	1.72 v.w.
3.12 v.w.	1.63 w (wide)
2.7 w (wide)	1.56 v.w.
2.58 e.w.	1.51 e.w.
2.43 m (wide)	1.425 e.w.
2.275 e.w.?	1.355 v.w. (wide)
2.15 v.w.	1.31 e.w.
1.82 v.w.	

Film 5

Some lines also present on Film 12

Wad

2.45 v.w., 1.401 v.w. } diffused

Film 13.

Hausmannite

3.07 m	1.30 e.w.?
2.85 v.w.	1.265 v.w.
2.73 h	1.235 e.w.
2.45 h	1.224 e.w.?
2.33 w	1.185 v.w.
2.125 e.w.	1.14 ?
2.025 w +	1.115 v.w.
1.815 ?	1.076 v.w.
1.77 w	1.055 e.w.?
1.725 e.w.	1.02 v.w. (wide)
1.685 w	
1.625 w	0.987 e.w.
1.56 m	0.978 e.w.
1.53 h—	0.965 e.w.?
1.427 w	0.936 e.w.?
1.375 e.w.	0.907 v.w.
1.33 + e.w.	0.861 e.w.
	0.845 v.w.

Films 6 and 9.

Lines on Film 9 wide and streaked.

Braunite

2.75	h	(wide)
2.37	w	"
2.15	w	"
1.9	e.w.	
1.81	e.w.	
1.75	e.w.	
1.66	h	(wide)
1.54	e.w.	
1.465	e.w.	
1.415	m	(wide)
1.36	w	

Film 8

Bementite

3.6	h		1.98	?	
3.05	w		1.90	?	
2.85	m	(wide)	1.810	w	(wide)
2.70	e.w.		1.735	e.w.	
2.56	v.w.		1.645	w +	
2.52	m	(wide)	1.597	e.w.	
2.425	e.w.		1.56	e.w.	
2.37	v.w.		1.445	v.w.	
2.265	e.w.		1.375	v.w.	
2.10	w				

Film 7

NOTES ON THE OCCURRENCES OF HAUSMANNITE.

Hausmannite, although not rare, is somewhat of an uncommon manganese mineral, so far as references in literature are concerned. The localities listed are Långban, Sweden, Ilfeld, Harz, and Ilmenau, Thuringia, Germany. Hausmannite is reported to occur at Batesville, Arkansas; Bromide, Oklahoma; San Jose, California, and Crescent Mine, Washington, in the United States; the occurrences in the Maritime Provinces are mentioned in the following pages.

Långban, Sweden.[11]—At Långban there are iron and manganese deposits in close association, but the manganese ores are practically free of iron, and vice versa. The orebodies occur in

[11] Långbansmineralien fran geologisk synpunkt," N. H. Magnusson, Review, Econ. Geol., 19, 1924, p. 687. Beck-Berg, "Abriss der Lehre von den Erzlagerstätten," 1922, p. 56.

interrupted but bedded deposits in dolomite which extends for some 4 kilometers along the strike. Magnusson considers that both types are replacements in the dolomite. First iron was deposited as oxide, along with silica forming a jasperoid, and manganese as oxide and carbonate. A later rise in temperature changed the hematite to magnetite and braunite to hausmannite with accompanying skarn minerals (hornblendes, pyroxenes and garnets). Beck considers that the deposits have resulted from contact metamorphism of original intercalated iron and manganese ores in the dolomite, with little or no introduction of material. The massive hausmannite is considered to have formed from braunite, while the disseminated hausmannite is supposed to be derived from pre-existing manganosite; both alterations taking place at high temperatures.

Ilfeld, Harz.[12]—In the Ilfeld district, the Rotliegendes is composed of alternating conglomerates, and sandy and clayey sediments with intercalated porphyrite extrusions. Overlying the Rotliegendes unconformably is the Zechstein. The manganese ores are found in association with iron ores, forming vein fillings and breccias in the porphyrite rocks. The mineral association is manganite, pyrolusite, varvisite, braunite, hausmannite, psilomelane and wad, with gangue minerals of calcite, barite, altered feldspar, and in one case rhodochrosite. Iron oxides are likewise intimately associated. The hausmannite is most plentiful in the upper part of the deposits; in depth, the iron ore, consisting of clayey hematite and kidney ore, increases in amount whereas the manganese content decreases.

It is thought that the manganese and iron lodes have been formed from descending solutions which derived their metal content from the overlying Zechstein and Rotliegendes.

Ilmenau, Thuringia.[13]—At Ilmenau, iron and manganese ores are found, which have a similar occurrence to those at Ilfeld, and are regarded to have a similar origin. The mineral association is hausmannite, braunite, radial and fibrous pyrolusite and psi-

[12] Beyschlag, Vogt and Krusch,—Truscott, vol. 2, 1916.
[13] *Idem.*

lomelane; barite is characteristic, with calcite and brecciated country rock. Limonite and hematite are occasionally associated, and in one occurrence take the place of the manganese minerals in depth.

Batesville, Arkansas.[14]—The deposits in the Batesville region occur in the Fernvale limestone and the Cason shale, or in residual clays derived mainly from these two formations. The oxides occur as replacement masses, mostly in clay but also in limestone, shale, chert, and sandstone. The mineral association is psilomelane, hausmannite, braunite, manganite, pyrolusite, and wad. Miser considers that "the oxides have been derived from manganese-bearing carbonates near the surface and have been deposited by cold waters of meteoric origin.

Others are of the opinion that the hausmannite has perhaps been formed by rising warm waters.

Bromide, Oklahoma.[15]—The occurrences of hausmannite in Oklahoma are found near Bromide. The ore occurs in limestone strata of Paleozoic age, and consists of hausmannite and psilomelane in association with calcite, siderite, and a manganese-magnesium-calcium carbonate; quartz, pyrite, and chalcopyrite may also be present. The hausmannite occurs either as fine crystallized masses of minute crystals, or as plumose masses, intergrown with the manganiferous carbonate.

Hewett states that the deposits are found in river valleys 100 to 150 feet below the surrounding plateau surface and that the country rock is very little weathered. The ore occurs along fractures or faults, or lies bedded with strata. He concludes that the hausmannite deposits have been formed "by the deposition of manganese minerals by warm waters rising along fractures", but does not commit himself to the origin of these waters. He intimates that they might be rising meteoric waters.

San Jose, California.[16]—At one time, near San Jose, California, a large boulder of manganese oxides existed, but this was broken up and shipped as manganese ore in 1918. The mineral asso-

[14] H. D. Miser and J. G. Fairchild, *Wash. Acad. Sci. Jour.*, 10, 1920.

[15] D. F. Hewett, U. S. Geol. Surv. Bull. 725–E, 1921.

[16] A. F. Rogers, *Amer. Jour. Sci.* (4), 48, 1919.

ciation in this boulder was tephroite, hausmannite, rhodochrosite, pyrochroite and psilomelane, named in their paragenetic order.

Rogers considers that this boulder had become detached from a manganese deposit in the Franciscan formation. "Although some doubt is attached to the original occurrence of this manganese ore, the presence of tephroite and hausmannite points to the high temperature nature of the deposit."

Washington.[17]—At the Crescent Mine, Washington, hausmannite is found in association with bementite and manganiferous carbonate along with quartz and iron oxides. The orebodies are found in an impure red limestone of probable Franciscan age, and are overlain by volcanic rocks of Tertiary age. The manganese is believed to have been originally deposited with the limestone as a carbonate. Later hot solutions migrating from the effusive rocks or their magma, converted the manganese present in the limestone into hausmannite and bementite.

MINERALOGY OF THE ORES OF THE MARITIME PROVINCES.

The manganese minerals distinguished in the ores of the Maritime Provinces are pyrolusite, manganite, hausmannite, braunite, psilomelane, wad, and rhodochrosite. Associated gangue minerals are calcite, barite, selenite, limonite, hematite, and the various minerals of a granite rock.

Of the ore minerals, pyrolusite is present in all the occurrences, except perhaps the deposits of wad, and varies in amount, frequently forming the predominating oxide mineral. It is believed to represent an alteration of other manganese oxides, mainly manganite, but also hausmannite and braunite. In these latter instances the writer can not say definitely whether the pyrolusite has been formed from an intermediate stage of manganite, or not, but in one or two instances such a transition was suggested.

Manganite is the next most common mineral and is found in the majority of the deposits, frequently being the most prevalent oxide present. This mineral was noted to form as an alteration

[17] J. T. Pardee, U. S. Geol. Surv. Bull. 795–A, 1927.

of hausmannite and braunite, but in most cases it appeared to be the original mineral. Its alteration to pyrolusite is quite characteristic, and all stages of replacement may be observed.

Psilomelane is a term that was used in the field to represent dense, hard material with a dark brown to black streak. Later microscopic work showed that some of the material so described was really braunite or dense hard manganite. As used in this paper it is modified, generally, to include hard dense material that gave no definite chemical reactions, and also is retained from field notes in some cases where no specimens were taken to represent this phase of the ore.

Hausmannite was distinguished in the ore from the occurrences at McCuish, and McVicar's farms, Cape Breton Island, Black Rock, Colchester County, Nova Scotia, and at Jordan Mountain and Markhamville, New Brunswick. At McVicar's farm, it is the predominating manganese mineral, with associated rhodochrosite and minor amounts of manganite and pyrolusite. At the other localities it is present in minor amounts.

Braunite was distinguished in the ore from Terra Nova, Cape Breton Island and Gowland Mountain and Markhamville, New Brunswick. The only occurrence of rhodochrosite noted is at McVicar's farm in association with hausmannite, and the carbonate has been formed later than the oxide mineral.

Of the gangue minerals calcite is always present in varying amounts. Barite and selenite are likewise common but not as persistent. Where present, the barite is of local occurrence, and appears to have formed at an intermediate stage in the oxide deposition, as crystals of this mineral are frequently observed in vugs within the ore and then minute crystals of the ore minerals can be seen on the barite. In thin sections of ores the barite is replaced by the manganese minerals. Much of the barite tested yielded traces of strontium. Selenite is frequently mentioned in the old reports from many of the occurrences but the writer did not see much of this mineral.

Limonite is common in varying amounts in a number of deposits, and in such occurrences as Bridgeville, Londonderry, Clif-

ton, and Torbrook, it is the main mineral with the manganese oxides as subsiduary occurrences. Hematite (probably goethite) is associated with these in the latter instances. In all cases observed the limonite was the earlier mineral, deposited in beautiful colloform structure; the manganese oxides are later and have been deposited in cracks and replaced the limonite in crystalline aggregates.

The sequence in the manganese oxides appears to have been hausmannite or braunite, altering to manganite and this to pyrolusite. In some instances braunite appears to be developing from some earlier deposited mineral, but what this is, is not known. The intermediate stage of manganite is not definitely established. Commonly manganite is the primary oxide deposited and this alters to pyrolusite. The sequence of the gangue minerals is not known, but as has been stated, calcite has been replaced by the oxides and is at times intermediate. Rhodochrosite formed after hausmannite and replaces it or forms incrustations in cavities in the ore. Barite and selenite are local and apparently an intermediate product of deposition. Limonite is invariably older than the manganese minerals in these deposits.

OCCURRENCE OF THE ORES OF THE MARITIME PROVINCES.

The most common occurrence of the ores is in the Lower Carboniferous limestone with its associated gypsum, shale, sandstones, and grits. The limestone is widespread throughout the Maritime Provinces, and is generally believed to underlie the beds of gypsum. This Lower Carboniferous limestone is persistently magnesian in contrast to the later Carboniferous limestone members, which have little or no magnesium in them. Analyses of this member made by E. Gilpin, Jr.,[18] from Cape Breton, Pictou, and Tennycape, showed the manganese content (determined as $MnCO_3$) to vary between 1.38 and 14.58 per cent. In these strata the ores occur as veinlets, nodules, and irregular replacements of the limestone, and where in contact with an underlying shale, there is a tendency for it to spread out along the shale-

[18] *Trans. Roy. Soc. Canada*, Sect. IV., Vol. II., 1884.

limestone contact. Ore in veins and nodules is also found in the shale, and thin stringers occur in sandstone, but these are of minor importance as compared to the limestone occurrences. Occurrences are found in older and younger sedimentary rocks and in the Triassic traps but these are of no importance economically. At New Ross valuable deposits of manganese oxides are found as veins in granite, and represent a replacement of carbonate veins by meteoric waters concentrating the original manganese content of these veins. Other deposits occurring in granite are located in Cape Breton, N. S., and at Gowland Mt., N. B., but these appear to have been formed on the surface of the granite mass in contrast to the New Ross occurrence. Bog ores are widespread throughout the provinces and in places are sufficiently large to form possible economic deposits of limited extent.

POSSIBLE ORIGIN AND MODE OF CONCENTRATION OF THE MANGANESE ORES IN THE MARITIME PROVINCES.

Time of Concentration.—In the preceding pages it was noted that the majority of the manganese deposits are associated with the Lower Carboniferous limestone. Because of this association the earlier reports assumed that the concentration of manganese took place during the minor epochs of elevation within the later Carboniferous and mainly in the general emergence during Permian time.

During the field investigation the writer observed little evidence to substantiate this view. The only deposits which might be used as evidence for this early concentration are those at Shepody Mountain, and Memel, Albert County, N. B. At these localities the oxides occur in such a manner that they suggest that the deposits were formed prior to, or accompanying the deposition of a Carboniferous conglomerate. In none of the other occurrences in the Carboniferous rocks are there younger strata overlying the ores in such a manner that they date the ore concentration prior to the deposition of the younger rocks.

At Tennycape estuary, and the Wheadon occurrence in Hants County, near Wolfville, Kings County, and along the north shore

of Cobequid Bay, occurrences are found in which the manganese oxides occur as veinlets in Triassic sediments, or as a replacement of the cement of these rocks. The widespread occurrence of bog ores throughout the Maritime Provinces is evidence of recent transportation and deposition of manganese. Again, in reviewing the literature on the occurrences in the Appalachian Province and Arkansas it is to be noted that the concentration of manganese which resulted in the present deposits in these regions is considered to have taken place during Cretaceous and Tertiary times.

From such evidence as this the writer suggests that the concentration of manganese into the deposits as now found in the Maritime Provinces took place subsequent to the Permian, perhaps in Tertiary time.

Source of the Manganese.—The source of the manganese is somewhat vague, and various strata and rock units are called upon to furnish the supply. Among these are the Lower Carboniferous sediments and their intercalated volcanics, and the effusive rocks of Triassic age.

Mode of Concentration.—In general it is believed that the manganese deposits of Nova Scotia and New Brunswick have been formed by meteoric waters which derived the manganese from the rocks through which they percolated, and deposited it in the form of the present orebodies. Those occurrences which contain hausmannite may possibly be exceptions to this general statement.

In reviewing the literature relating to a number of occurrences of hausmannite, and also from personal discussion with Dr. W. Lindgren, it seems that hausmannite is generally conceded to have been formed by rising warm or hot waters. The deposits at Långban certainly point to high temperature formation. In the hausmannite occurrences of the Maritime Provinces, there is no evidence for or against such a view. If one assumes that they have been formed by warm or hot waters, then the source of these must be established.

Since the deposits were formed in Lower Carboniferous strata, subsequent to their consolidation, the only igneous activity that

can be assumed to have furnished the heat necessary is the Triassic eruptive rocks. If these rocks furnished the heat, and perhaps also the solutions that resulted in the deposition of the hausmannite, then it seems to the writer that deposits containing hausmannite should be found in proximity to the occurrences of the Triassic effusives. However, in reviewing the location of the hausmannite occcurrences in respect to their geological environment it is seen that they are considerably removed from an occurrence of Triassic flow rocks, and moreover, those deposits of manganese which are found in close proximity to the effusive rocks contain no hausmannite. The exception to these statements is the occurrence at Black Rock, Colchester County, Nova Scotia, which is in close association with the Triassic members. In this occurrence the hausmannite is found in small scattered bunches within the other manganese oxides, but it might be well to mention here that the manganese oxides have been deposited later than associated limonite.

In conclusion the writer does not like to say that the hausmannite in the Maritime occurrences has not been deposited by heated waters, but at the same time he does not think there is much evidence to support the view that it has been formed in this way.

The bog ores are considered to have formed, and to be forming now, from meteoric waters that have derived their manganese content from the underlying strata. Deposition of the manganese minerals results from bacterial action, reaction with organic acids and decomposing organic material, and by oxidation.

The remaining deposits have been formed from descending surface waters which after seeping through the surrounding rocks and dissolving the manganese contained in them, became concentrated (in direction of flow) along the better established lines of underground drainage, and here deposited their content by replacement of the adjoining limestone and by oxidation. Such deposition need not have taken place in the zone of active oxidation but probably occurred at greater depths.

Transportation of the Manganese.—The manner in which the

manganese was transported, prior to its deposition in the deposits of the Maritime Provinces, is a subject that is open to speculation, and the writer approaches the problem with timidity and offers the following suggestions for what they are worth.

That the bicarbonate of manganese plays an important rôle in the transportation of manganese is amply borne out by many instances in nature—deposits of iron and manganese about mineral springs—and by experimental data.[19]

The manganous sulphate is quite soluble (53.2 parts per 100 of cold water)[20] and moreover, J. W. Mellor[21] states that manganous salts are stable in neutral or acid solutions. The experiments of F. P. Dunnington[22] also show that, given a source of sulphuric acid, the sulphate may be an important agent in the transportation of the manganese. These experiments also showed that manganous sulphate solution was not affected by air alone, but in the presence of $CaCO_3$ manganese oxide was formed.

It has been noted in the preceding pages that the manganese deposits in the Lower Carboniferous strata, are frequently in close association with gypsum beds. Moreover, as evidenced by springs issuing from the gypsum-bearing horizons, chemical changes within the gypsum are now producing H_2S, and free sulphur, and very likely there is produced some H_2SO_4. Such waters as these, in percolating through a manganiferous limestone, would produce a chemical readjustment resulting in the formation of calcium sulphate, and carbon dioxide. With these substances present the manganese could enter into solution either as the bicarbonate or sulphate. If there was a deficiency or lack of air at the place of solution, the sulphate would remain dissolved until the channels of main underground circulation were reached, and here, in the presence of oxygen and calcium carbonate, would precipitate as the oxide. The manganese bicarbonate might also be oxidized at the same time.

[19] M. V. Vincent, *Compte Rendu*, 162, p. 259, 1916. L. Dieulafait, *idem*, 101, 1885, quoted by F. W. Clarke, U. S. Geol. Surv. Bull. 695, 1920, p. 533.

[20] "Handbook of Chemistry and Physics," 12th Ed., 1927.

[21] "Modern Inorganic Chemistry," London, 1914, p. 478.

[22] *Amer. Jour. Sci.* (3), 136, 1888, p. 175.

At this point it may be recalled that many of the occurrences in the Lower Carboniferous limestones are found as irregular veinlets trending down the general dip of the beds and nearly at right angles to the bedding. In the vicinity of shale strata the attitude of the orebody changes and it widens out and extends down the dip parallel to the bedding. In other places the oxides may form the cement to a calcareous breccia. Also the old reports remark that the ore was sometimes found on a water-worn surface of limestone. Ed Gilpin, Jr.,[23] states of the Tennycape mine, "The ore occurs in irregular nests, and in seams eroded on the bedding planes and cross fractures . . . the ore has been deposited . . . in the openings worn by the action of water on the limestones. Specimens may be obtained showing pyrolusite, cementing water-worn pieces of limestone, and surrounding nodules of the bedrock which have resisted erosion."

From these considerations the writer suggests that the manganese was transported not only as the bicarbonate but also as the sulphate.

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[23] *Trans. Roy. Soc. Canada*, vol. II., pt. IV., p. 10, 1884.

SOLUTION, TRANSPORTATION AND PRECIPITATION OF IRON AND SILICA.

E. S. MOORE AND J. E. MAYNARD

PART III.

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GENERAL DISCUSSION OF THE PRECIPITATION OF SILICA.

Summary of experimental results.

The experiments so far carried out on the precipitation of silica show that it is precipitated by electrolytes, such as are in sea water, from three types of solutions containing silica, namely: sodium silicate solutions, dialyzed sodium silicate solutions, and sodium silicate solutions that have first been mixed with hydrochloric acid and then dialyzed. In each type of solution, with perhaps the exception of the sodium silicate, the silica is in the colloidal form. In the case of the undialyzed sodium silicate solutions the greater portion of the silica also is in the colloidal condition, since at a dilution of 30 parts per million hydrolysis is practically complete. In this case, however, modifying condi-

tions are to be expected because the excessions were not removed by dialysis.

It has been shown in the previous sections that the various electrolytes did not have the same precipitating effect on these different types of colloidal silica. In order, if possible, to explain this irregularity, Tables II., IV., and V. were summarized and the summary is given in Table VII.

Table VII. shows that sodium chloride, providing time is taken into consideration, is a very efficient precipitant of silica from silica hydrosols formed by dialyzing dilute sodium silicate solutions. Sodium chloride is, however, a very inefficient precipitant in undialyzed sodium silicate solutions and in sodium silicate solutions that were mixed with hydrochloric acid and then dialyzed. Magnesium sulphate in no case acts as a precipitant. Sea salt is the most efficient precipitant in all cases. It is most efficient in dialyzed sodium silicate solutions, then in undialyzed sodium silicate solutions, and finally in sodium silicate solutions that were mixed with hydrochloric acid and then dialyzed. Calcium carbonate and carbon dioxide, that is, calcium bicarbonate, is a powerful precipitant of undialyzed sodium silicate solutions, whereas it is very inefficient in the other two types of solutions.

Theory of electrolytic precipitation.

It is very difficult to give an adequate explanation for the precipitation of silica hydrosols by electrolytes. Taylor [94] states that colloidal silica is positively charged in acid solutions, and negatively in alkaline or very feebly acid solutions. The silica micelle receives the electric charge by the adsorption of positively or negatively charged ions. And it is generally accepted that silica hydrosols are peptized by adsorbed ions. The colloidal particles are all charged negatively in alkaline solution and consequently they repel each other, thus preventing coagulation of the particles. The manner of formation of the silica hydrosol, therefore, is of importance, for it determines the ion adsorbed and it in turn determines the coagulating ion.

[94] Taylor, W. W., "Chemistry of Colloids and some Technical Applications," 1915.

TABLE VII.

PARTIAL SUMMARY OF TABLES II., IV., AND V.

Precipitation of Silica from three kinds of Silica Solutions containing 30 Parts per Million SiO_2.

Exp.	Reagent Added to Solution.	Days Reagent in Contact with Solution.	Table II.		Table IV.		Table V.	
			SiO_2 in Ppt. and Filtrate from Sodium Silicate Solution.		SiO_2 in Ppt. and Filtrate from Dialyzed Sodium Silicate Solutions.		SiO_2 in Ppt. and Filtrate from Dialyzed HCl and Sodium Silicate Solutions.	
			Gms. SiO_2 in Ppt. Recalc. to p.p.m. of Original Filtrate.	P.p.m. SiO_2 in Filtrate.	Gms. SiO_2 in Ppt. Recalc. to p.p.m. of Original Filtrate.	P.p.m. SiO_2 in Filtrate.	Gms. SiO_2 in Ppt. Recalc. to p.p.m. of Original Filtrate.	P.p.m. SiO_2 in Filtrate.
A 1	Blank	25	1.5	29.5	1.0	27.5	6.0	28.0
2	"	75	3.5	27.0	2.5	25.5	12.0	24.0
B 1	NaCl, 34.400 p.p.m.	25	5.0	28.0	10.0	23.5	6.0	24.0
2		75	7.5	25.0	20.5	11.5	8.0	26.0
C 1	$MgSO_4$ 34.400 p.p.m.	25	4.5	28.5	1.5	28.0	4.0	28.0
2		75	4.0	28.0	1.0	28.5	6.0	26.0
D 1	Sea Salt 34.400 p.p.m.	25	9.0	21.5	12.5	24.5	10.0	24.0
2		75	16.0	17.0	21.0	12.0	16.0	20.0
E 1	$CaCO_3+CO_2$ for 1 hr.	25	6.5	25.5	2.0	28.0	8.0	24.0
2		75	12.0	19.5	1.5	29.0	12.0	28.0

According to Hardy,[95] hydrosols are precipitated by electrolytes, negative colloids by the positive ions, and positive colloids by the negative ions. Coagulation occurs when the particles are completely discharged. An isoelectric point has, therefore, been reached. Schulze[96] points out that the precipitating power of the ion increases with the valency. These two laws are modified by Freundlich[97] who states that the coagulating power of the ions depends upon the adsorbability of the active ion as well as upon the valency, the latter influence depending upon the adsorbability.

Freundlich[98] has divided the sols into two groups. Following Penin's nomenclature, he calls them hydrophobic and hydrophilic sols, since we are generally dealing with aqueous solutions. Hydrophilic sols are those that have a strong affinity for water. They "imbibe it" and become hydrated. It is probable, therefore, that the micelle or disperse phase of these sols consists of an amorphous, solid, aqueous solution. To this type belong such substances as gelatine, albumin, colloidal silica, etc. In this type of sol the electrical properties of the particles are considerably modified and the stability toward electrolytes is often very striking. Hydrophobic sols are those which appear to hate water, that is, they become little hydrated. To this type belong such substances as sulphides, metals, and similar substances. They are coagulated by electrolytes in small concentrations and this effect is directly connected with the electrical properties of the colloid particles.

From this discussion it is seen that colloidal silica is not precipitated by electrolytes according to the laws of Schulze and Hardy. It is a hydrophilic sol and consequently—although it is peptized by adsorbed ions—these ions are very difficult to neutralize because of the modifying effect of the "imbibed" water and other effects that up to date are not understood. It is not to be

[95] Hardy, W. B., *Proc. Roy. Soc.*, 66, p. 1110, 1899.

[96] Schulze, H., *Jour. Prak. Chem.*, 25, p. 431, 1882.

[97] Freundlich, H., Hatfield, H. S., "Colloid and Capillary Chemistry," p. 420, 1926.

[98] *Idem*, pp. 362–365.

expected, therefore, that ions of high valency have greater precipitating power with silica hydrosols. This was found to be the case, as a study of Table VII. shows, for the divalent magnesium and calcium ions are not as a rule as effective precipitants as the univalent sodium ions.

Application to Problem.—It is impossible to give a satisfactory explanation of the varied precipitating effects of the different electrolytes on the three types of colloidal silica solutions given in Table VII. Sodium chloride is a very inefficient precipitant of silica from undialyzed sodium silicate solutions containing 30 parts per million silica whereas it is a very efficient precipitant in dialyzed sodium silicate solutions containing the same proportion of silica. This difference is very difficult to explain since in both types of solutions the colloidal silica was formed by the hydrolysis of sodium silicate, $Na_2SiO_3 + 2H_2O \rightleftarrows H_2SiO_3 + 2NaOH$, and it was stabilized by the adsorption of the OH ions. The only explanation occurring to the writers is that the small quantity of ionic or molecular silica in the undialyzed solution exerted a protective action on the micelle, causing the adsorbed OH ion to be more strongly held, and, therefore, to be less susceptible to the action of electrolytes.

Sodium chloride acts as a very inefficient precipitant on the third type of colloidal silica, made by dialyzing a mixture of water glass and hydrochloric acid. In this case the colloidal silica was formed according to the following equation:

$$Na_2SiO_3 + 2HCl \rightleftarrows H_2SiO_3 + 2NaCl.$$

Here it is probable that the colloidal silica was stabilized by the adsorption of the negative Cl ion. This ion is adsorbed more strongly than the OH ion of the previous type and consequently precipitation is prevented. Magnesium sulphate not only failed to act as a coagulator in the three types of silica hydrosols but it appeared to act as a stabilizer. This stability is probably due to the large excess of magnesium sulphate causing it to act as a peptizer, for according to Bancroft[99] if the point of electrical

[99] Bancroft, W. D., "Applied Colloid Chemistry," p. 222, 1921.

neutrality is overrun the suspension may become stable again by the preferential adsorption of the ion having the opposite sign.

Calcium bicarbonate acts as an efficient precipitant only in undialyzed silica hydrosols, it being very inefficient in the dialyzed hydrosols. Freundlich [100] states that silicic acid freshly separated from the silicate is not colloidal but is present in true solution; it diffuses rapidly through membranes but gradually becomes coarser until true colloidal silica is obtained. It may be possible, therefore, that in the undialyzed solution of sodium silicate the greater portion of the silica was still in true solution as ionic silicic acid, and that the calcium bicarbonate was able to act as an efficient precipitant of the ionic silica before it had time to agglomerate to the colloidal size.

Conclusions.—The experiments show conclusively that silica may exist in nature as sodium silicate and colloidal silica. The colloidal silica may be stabilized in a variety of ways and it is precipitated by electrolytes, providing sufficient time is available. The rate of precipitation may be increased by changing the solutions from acid to slightly alkaline. For example, Gruner [101] obtained a solution of 120 parts per million silica by the action of $N/50$ sulphuric acid on serpentine, and he treated it with sodium carbonate until slightly alkaline. All the silica coagulated immediately. Colloidal silica may be stabilized by some "sol-former" which may be an inorganic acid, an alkali, or organic matter. The rate of precipitation by electrolytes, if precipitation does occur, depends upon the kind of ion adsorbed, the tenacity with which the adsorbed ion is held, the quantity and manner in which the precipitating agent is added, and a great many other factors unknown at present.

MUTUAL PRECIPITATION OF FERRIC OXIDE AND SILICA HYDROSOLS.

The experiments to date show that hydrosols of ferric oxide and silica are quite stable, taken separately, and that they are both precipitated by electrolytes such as are in the sea, the ferric oxide

[100] *Op. cit.*, p. 628.

[101] Gruner, J. W., ECON. GEOL., 17, pp. 442–446, 1922.

coming down almost immediately and the silica requiring a considerable period of time for precipitation. Although ferric oxide and silica hydrosols are quite stable, taken separately, it was assumed that they might precipitate each other on mixing. Such an assumption has been found to be correct, for on adding a given quantity of ferric oxide hydrosol to a silica hydrosol practically all of the iron was precipitated almost immediately. It was found, also, that a small amount of the silica had been deposited along with the iron. Consequently if iron and silica are to be carried in nature as colloids some substance must be present to act as a protector in order to prevent them from coagulating each other.

The literature [102] concerning the mutual precipitation of hydrosols treats the phenomenon as an electrical one by which the positively charged particles of one hydrosol neutralize the negatively charged particles of the other; but since Freundlich and Nathansohn [103] discovered that arsenious sulphide hydrosol and sulphur hydrosol precipitate each other—although both are negatively charged—the chemical precipitation theory has been brought forward. Lottermoser [104] was the first to suggest a chemical mechanism for the mutual precipitation of colloids, and recently this has been studied quantitatively by Thomas and Johnson.[105] They state that the mutual precipitation of ferric oxide and silica hydrosols is due to the removal of the peptizing agents by chemical action between them. They found that on mixing 5.3 c.c. ferric oxide hydrosol containing 0.0191 mole (3,050 parts per million) with 1 : 10 c.c. of silica hydrosol containing 0.01221 mole of silica (1,343.6 parts per million), complete coagulation took place. When they mixed ferric oxide sols containing 305 parts per million ferric oxide with silica sols containing 268 parts per million silica, complete precipitation occurred only when the total reaction

[102] Linder, S. E., and Picton, H., *Jour. Chem. Soc.*, 71, p. 586, 1897. Zsigmondy, R., Spear, E. B., "Chemistry of Colloids," p. 56, 1917. Bechhold, H., *Zeit. Physik. Chem.*, 48, p. 385, 1904. Henri, V., *Compt. Rend. Soc. Biol.*, 55, p. 1666, 1903. Freundlich, H., Hatfield, H. S., "Colloid and Capillary Chemistry," p. 477, 1926.

[103] Freundlich, H., and Nathansohn, A., *Kolloid Zeit.*, 28, p. 258, 1921.

[104] Lottermoser, Von A., *Kolloid Zeit.*, 6, p. 78, 1910.

[105] Thomas, A. W., and Johnson, L., *Jour. Amer. Chem. Soc.*, 45, p. 2532, 1923.

mixture contained 172 parts per million ferric oxide and 117 parts per million silica. Similarly they found that ferric oxide sols containing 61 parts per million ferric oxide and 53 parts per million silica would completely precipitate each other on mixing, provided the concentration of the total reaction mixture was 32 parts per million ferric oxide and 25 parts per million silica. When ferric oxide hydrosols containing 30.5 parts per million ferric oxide, and silica hydrosols containing 53 parts per million silica are mixed in varying proportions, precipitation is very slow and in no case is it complete. Thus when the total reaction mixture contains 16 parts per million ferric oxide and 25 parts per million silica there is partial precipitation, and the concentration can be varied through wide ranges in such highly diluted solutions without danger of complete precipitation. These results of Thomas and Johnson agree exceptionally well with those obtained by the writers. (See Table VIII.)

In the writers' experiments the ferric oxide and silica hydrosols

TABLE VIII.

PRECIPITATION OF FERRIC OXIDE AND SILICA HYDROSOLS ON MIXING.

Exp.	25 c.c. of Fe_2O_3 soln. containing 20 p.p.m. Fe_2O_3 mixed with 25 c.c. of SiO_2 soln. containing 60 p.p.m. SiO_2.		Analysis of Filtrate.	
	Type of ferric oxide soln.	Type of silica soln.	Fe_2O_3 in p.p.m.	SiO_2 in. p.p.m.
1	Made by dialyzing hydrolyzed $FeCl_3$	Dialyzed sodium silicate	1.5	29
2	Made by dialyzing hydrolyzed $FeCl_3$	Undialyzed sodium silicate	2.5	23
3	Made by dialyzing hydrolyzed $FeCl_3$	Sodium silicate which had been neutralized with HCl and then dialyzed	1.0	32

were made of such concentrations that, on mixing, the total reaction mixture contained 10 parts per million ferric oxide and 30 parts per million silica. This was done because, according to Gruner,[106] the ratio of iron to silica in the cherts of the Biwabik iron formation is one part of iron to three parts of silica. The

[106] Gruner, J. W., ECON. GEOL., 17, p. 450, 1922.

experiments were performed with one type of ferric oxide hydrosol and the three types of silica hydrosols used in the experiments on the precipitation of ferric oxide and silica by salts such as exist in the sea. The results obtained are given in Table VIII.

STABILIZATION OF SILICA AND FERRIC OXIDE HYDROSOLS.

Since mixing silica and ferric oxide hydrosols in such concentrations as might exist in nature caused the precipitation of a greater part of the ferric oxide, a number of experiments were carried out to determine, if possible, whether some natural substance could be found which would make them stable in the presence of each other. Varying concentrations of inorganic salts had no effect, and this was to be expected because colloidal ferric oxide is very susceptible to the influence of electrolytes.

Riffard [107] found that a concentrated solution of sugar in water would prevent the precipitation of hydrous oxide of iron, and Bancroft [108] states that invert sugar is about seven times as effective as cane sugar in holding up hydrous ferric oxide. The writers found that colloidal ferric oxide that had been dialyzed in tap water would coagulate in a few weeks, but that if a small quantity of peat solution was added to it the solution would remain stable for many months. This experiment suggested that such a natural organic substance might stabilize colloids of silica and ferric oxide, and thus permit their mutual transportation in solution. An experiment proved that precipitation was prevented by adding a small quantity of peat solution to the silica hydrosol before the addition of the ferric oxide hydrosol.

Although colloidal silica and ferric oxide are made stable in the presence of each other by the brownish solution that is extracted by water from decaying plants, it was decided to determine whether the organic matter in concentrations such as are in some river waters would have the same stabilizing power. In order that conditions might be as nearly natural as possible the colloidal silica and ferric oxide were made by dialyzing in tap water. They

[107] Riffard, M. E., *Compt. rend.*, 77, p. 1103, 1873.
[108] Bancroft, W. D., "Applied Colloid Chemistry," p. 168, 1921.

were thus prepared in the presence of considerable quantities and concentrations of electrolytes. The peat solution was made previously by immersing a handful of dried peat in distilled water and allowing the water to remain in contact with the peat for a year, when the brown solution was removed by filtering.

A partial analysis of the peat solution (after evaporating and drying at 110° C. for 12 hours) gave:

	Per Cent.
Organic matter	93.51
Silica	1.62
Ferric and aluminium oxide	3.67
Calcium oxide	2.03
Magnesium oxide	Trace
	100.83

Total solids in solution, parts per million	986
Organic matter, parts per million	922

The silica and ferric oxide hydrosols, as made above, were analyzed, and then diluted so that the silica hydrosol contained 60 parts per million silica and the ferric oxide hydrosol 20 parts per million ferric oxide. Thus, on mixing, the total reaction mixture would contain 30 parts per million silica and 10 parts per million ferric oxide. To 50 c.c. of the silica hydrosol was added one c.c. of the peat solution and then 50 c.c. of the ferric oxide hydrosol was poured in, and the mixture well agitated. There was no sign of coagulation and even at the end of two weeks very little precipitation had occurred. This result shows that one c.c. of the peat solution in a total volume of 201 c.c. is able to exert sufficient protective action to prevent the coagulation of the silica and ferric oxide. Thus a total reaction mixture containing 9.95 parts per million colloidal ferric oxide, 29.85 parts per million colloidal silica, and 4.5 parts per million organic matter remained stable, in the presence of considerable quantities of electrolytes, for two weeks. Natural streams, therefore, in which the content of organic matter is at least 4.5 parts per million, will have no difficulty in transporting 30 parts per million colloidal silica and 10 parts per million colloidal ferric oxide. The experiments were

conducted, also, using 2 c.c. of peat solution, and up to two months the reaction mixture showed no sign of coagulating. This last result shows that 9 parts per million of natural organic matter is a very efficient protector for colloidal silica and ferric oxide. That 9 parts per million organic matter is not excessive for rivers is shown by Clark.[109] He gives an average of about 12 parts per million organic matter for the rivers of the world.

PRECIPITATION OF MIXED SILICA AND FERRIC OXIDE HYDROSOLS STABILIZED BY ORGANIC MATTER.

In the previous sections it has been shown that electrolytes, such as are in sea water, with time, precipitate colloidal silica solutions, and almost immediately precipitate colloidal ferric oxide solutions. It has been shown, also, that colloidal silica and ferric oxide solutions mutually precipitate each other, but that the two remain stable in the presence of a small quantity of organic matter and considerable quantities of electrolytes. It should be possible, therefore, under favorable conditions, for considerable quantities of iron and silica to be transported as colloids in the presence of each other in natural waters. In the previous experiments on the precipitation of colloidal silica and iron solutions by electrolytes practically all the colloidal solutions were taken separately. Although it would naturally be expected that very similar results would be obtained on adding electrolytes to colloidal solutions containing silica and ferric oxide stabilized by organic matter, it seemed advisable to make certain of this point.

A colloidal solution was prepared by the method indicated in the previous section. It contained 10 parts per million ferric oxide, 30 parts per million silica and 9 parts per million organic matter. To 100 c.c. of this solution was added sea salt in the proportion of 34,400 parts per million. By the next morning practically all the iron had been coagulated, whereas the greater part of the silica still remained stable.

In the section on the precipitation of ferric oxide hydrosols by electrolytes, it was shown that sea salt in the proportion of

[109] *Op. cit.*, p. 110.

34,400 parts per million coagulates the iron in three days from a solution formed by oxidizing ferrous bicarbonate in the presence of a small amount of peat solution. The ferrous bicarbonate solution was obtained by the action of carbonated water on norite, and it contained also 73.8 parts per million silica, which, however, at the end of three days showed no signs of coagulating.

These experiments show that, in mixed colloidal solutions containing ferric oxide and silica stabilized by organic matter, ferric oxide is much more sensitive than silica to ocean electrolytes.

This differential precipitation of iron and silica suggests a possible explanation for the origin of banded iron and silica formations.

BANDING OF SILICA AND IRON.

A perusal of the literature gives no adequate explanation of the characteristic banding of iron and silica in the pre-Cambrian iron formations. Van Hise and Leith [110] state that, when ferrous silicate comes into contact with calcium carbonate, ferrous carbonate is precipitated. The precipitate of ferrous carbonate is flocculent, settles slowly and in settling shows a distinct tendency to aggregate into bands separated by varying amounts of free silica. Collins [111] points out that banded iron and silica can be formed by precipitation from ascending heated mineralized waters spreading out in depressions, the iron and silica being precipitated by cooling and evaporation, a new supply of solution forming a new band.

The writers formed banded iron and silica by Liesegang's method. A mixture of equal volumes of 1.16 density water glass and 3*N* sulphuric acid was made 0.1*N* with respect to ferric chloride. The solid gel formed in a day or two and was then covered with ammonium hydroxide. At the end of a month a series of bands of ferric hydroxide developed throughout the silica gel. It does not appear, however, that this explanation is applicable to the formation of a banded iron formation of great thickness.

[110] Van Hise, C. R., and Leith, C. K., U. S. Geol. Surv. Mon. 52, p. 520, 1911.

[111] Collins, W. H., Quirke, T. T., and Thomson, E., Geol. Surv. of Canada, Mem. 147, p. 75, 1926.

Further experiments were carried out to determine whether banding of iron and silica could be brought about by simple sedimentary processes.

Freshly precipitated colloidal ferric hydroxide and gelatinous silica, in the proportion of three parts silica to one of ferric hydroxide, were well agitated in a tall vessel containing sea water, and then allowed to settle. In a few hours the greater portion of the ferric hydroxide, along with considerable silica, settled to the bottom of the vessel. The ferric hydroxide precipitate was of a light reddish brown color. On examining the vessel several days later it was found that this reddish brown layer graded upward into a layer of almost pure white gelatinous silica. This showed that the silica required a longer period than the iron oxide to settle under the force of gravity. The electrolytic content of the water, in all probability, played a part, for when the experiment was repeated with distilled water the color change was hardly noticeable.

This differential settling of a disturbed deposit of gelatinous silica and ferric hydroxide may be important geologically, for in this manner a banding may be instigated which at a later stage may be considerably enhanced by metamorphism.

Another experiment was carried out as follows:

A tall cylindrical vessel was filled to the 500-c.c. mark with water and sufficient sea salt added to give it just twice the electrolytic composition of the ocean. A colloidal solution, 500 c.c. in volume, was prepared containing 20 parts per million ferric oxide, 60 parts per million silica and 18 parts per million organic matter. This colloidal solution was allowed to flow into the vessel, bringing its electrolytic composition to that of the ocean and at the same time its colloidal content to 10 parts per million ferric oxide, 30 parts per million silica and 9 parts per million organic matter. In a very short time the greater portion of the iron coagulated on the bottom of the vessel. There was no evidence of a precipitate of colloidal silica. However, on examination four months later, it was found that an appreciable layer of gelatinous silica had been deposited on top of the ferric hydroxide.

The contact between the ferric hydroxide and the silica was quite definite. The upper surface of the gelatinous silica was very irregular and consisted of spherical and elliptical globules of silica hydrogel. A fresh supply of colloidal silica and iron, stabilized by organic matter, was allowed to flow into the vessel. Within a few days a new layer of ferric hydroxide was deposited on the gelatinous silica, filling the irregularities and cavities and then forming a definite layer. There is no doubt that banded silica and iron can be formed in nature by this process provided a periodic supply of silica and iron is available.

In order, if possible, to strengthen this idea that banded iron and silica can be formed by the differential precipitation of colloidal iron and silica by electrolytes such as exist in the ocean, the following experiment was performed:

A sample of the solution formed when carbonated water acted on 48-mesh norite for 70 days was obtained. The solution contained 36.4 parts per million ferric oxide in the form of bicarbonate and 73.8 parts per million silica. To the solution was added 16 parts per million organic matter, and air was bubbled through it for three days in order to oxidize the iron. Sea salt in the proportion of 34,400 parts per million was next added to the solution. At the end of three days practically all the iron had been precipitated as a flocculent, reddish brown mass. The tube containing the solution was stoppered and owing to the absence of the investigator was not examined again for 230 days. Examination at the end of this time showed that a layer of gelatinous silica had been deposited on top of the ferric hydroxide. This layer of silica was not a homogeneous mass, but consisted of a great number of elliptical and spherical globules of gelatinous silica. These globules, due to a slight agitation of the tube, rolled around on the layer of ferric hydroxide beneath, and accumulated a thin coating of oxide, giving them a much darker appearance.

A quite definite line could be seen between the ferric hydroxide and the later accumulation of gelatinous silica. There seems to be little doubt that in this case, also, the addition of a new supply of colloidal iron and silica would cause the formation of a second series of bands.

From these experimental results the writers suggest that the banding in some of the pre-Cambrian iron formations could be brought about at the time of their deposition through the differential coagulation of the iron and silica by the electrolytes of the sea.

SEDIMENTATION OF IRON ORES WITH SPECIAL REFERENCE TO THE BANDED IRON FORMATION OF THE LAKE SUPERIOR REGION.

Previous Views on the Origin of the Banded Iron Formations of the Lake Superior Region.—Much has been written on the origin of the Lake Superior iron ranges, and numerous theories have been put forward to explain their origin, but as these have been summarized and discussed many times they will be dealt with very briefly. That the iron formations are of sedimentary origin is accepted by the great majority of geologists. The main points of difference in the various theories are: the source of the iron and silica, the means by which they were transported and precipitated, and the form in which they were originally laid down.

Leith [112] has summarized the earlier literature on the genesis of these formations, and Gruner,[113] the more recent. In their work on the Geology of the Lake Superior Region, Van Hise and Leith [114] conclude that all the important Lake Superior iron-bearing formations are very similar in origin. They believe that they all originally consisted of a chemical precipitate of cherty iron carbonate and greenalite which has since been altered in many places. The iron salts going to form the iron-bearing formation were contributed to the ocean partly by weathering when the igneous rocks were hot or cold, but mostly by direct contribution of magmatic waters from the igneous rocks and by direct reaction of the sea waters upon hot lavas. They state further that the iron may have been carried as a ferrous salt of silicic, carbonic, sulphuric, hydrochloric or other acids. They

[112] Leith, C. K., U. S. Geol. Surv. Mon. 43, p. 31, 1903.
[113] Gruner, J. W., Econ. Geol., 17, p. 446, 1922.
[114] Van Hise, C. R., and Leith, C. K., *op. cit.*, pp. 516–518.

base their conclusions on the large masses of contemporaneous basic igneous rocks which could supply the iron.

Collins [115] believes that the Michipicoten iron ranges were formed "by ascending, heated, mineralized waters at many loci in a land area of great volcanic activity." The heated volcanic waters, mineralized with carbon dioxide, iron, silica, and sulphur, flowed over the surface and collected in depressions. These mineralized waters permeated the volcanic rocks that formed their basin, converting them into carbonates and sulphides. On evaporation and cooling the waters gave up their content of iron and silica, forming the banded silica member of the iron formation.

Gruner [116] has very carefully marshaled the evidence against the direct contribution of the silica and iron by the magma. No further discussion will be given here except to state that the writers believe that the iron and silica going to make up part of the Lake Superior iron formations were only to a minor extent contributed directly from magmatic springs and submarine lava flows, and that ordinary conditions of weathering, transportation, and deposition aggregated the silica and iron of the iron ranges.

Gruner [117] concludes that the source of the iron and silica that went to make up the Biwabik formation was the large land areas in North America that were covered largely with greenstones and basalts. The climate was humid and probably tropical or subtropical, causing abundant land vegetation of a low form which resulted in rapid decay of the rocks with concomitant solution of large quantities of iron and silica. He further concludes that most of the iron was carried to the basin of deposition as organic colloids, or adsorbed by organic colloids, and along with the colloidal silica was precipitated chiefly by algæ and bacteria. Relatively small quantities of colloidal silica and iron were precipitated by inorganic reactions. In special cases these colloids united to form amorphous iron silicates.

Recently a paper has come to hand by Gill [118] on the "Origin

[115] Collins, W. H., Quirke, T. T., and Thomson, E., Geol. Surv. of Canada, Mem. 147, p. 75, 1926.

[116] *Op. cit.*, pp. 447–452.

[117] *Idem*, p. 457.

[118] Gill, J. E., Econ. Geol., 22, pp. 687–728, 1927.

of the Gunflint Iron-Bearing Formation." He states that, in part at least, the origin of the Gunflint formation was similar to that of modern glauconite beds. The decomposition of iron-bearing silicates was the chief source of the iron and silica, these being carried to the sea by rivers, principally as colloids stabilized by protective agents. Precipitation was brought about by mingling of solutions from different sources. The bulk of the precipitate consisted of gelatinous silica and iron compounds which may have been chemically rearranged during or shortly after precipitation. These included hydrated ferrous silicate and silica, hydrated ferric oxide and silica, and in some places all three of these substances formed the final product. Locally ferrous carbonate was formed by a reaction between hydroxide, or greenalite, and organic matter.

Attention is called to the work of Cayeux[119] on the formation and alteration of the Palæozoic and Mesozoic oölitic ores of France, and to the possibility of their method of formation being applicable to the granular portions of the pre-Cambrian iron formations. He believes that the oölites and granules were all originally deposited, under shallow water conditions, as calcium carbonate, their deposition being the result of some sort of bacterial action. These calcium carbonate oölites and granules were altered to chlorite, iron carbonate, and hematite by submarine metamorphism before being consolidated into ore. The iron solutions bringing about the metamorphism were contributed to the sea by iron-rich streams. He considers the demolition of chains of mountains an essential factor in the genesis of sedimentary iron ores and oölitic ores in particular.

Plant Life in the Pre-Cambrian.—Since the oldest definitely accepted record of fossil land plants only goes back to the Silurian some students may argue that Gruner's assumption of abundant land vegetation in the Huronian is erroneous, but there is little doubt that plant life, whether land or water, did exist. Sea weeds (algæ) are known with certainty to have lived during Cambrian, Ordovician and Silurian times. More recently,

[119] Cayeux, L., "The Oölitic Ores of France," vol. I., 1909; vol. II., 1922.

due to the work of Walcott,[120] Moore,[121] Grout and Broderick,[122] Broderick,[123] Gruner,[124] and Gill,[125] it seems reasonably certain that minute organisms were present and widespread in Animikie time, including algæ, bacteria, and probably bacilli. Lull states that the evidence is positive for the existence of algæ among plants during this period. Grabau[126] remarks that the assumption of sparseness of land vegetation during the pre-Cambrian may be in error, as the sediments contain much carbonaceous matter. As long ago as 1888 Sir William Dawson[127] said: "It is deserving of notice that if the Laurentian graphite indicates vegetable life, it indicates this in vast profusion. That incalculable quantities of vegetable matter have been oxidized and have disappeared we may believe on the evidence of the vast beds of iron ore; and in regard to that preserved as graphite, it is certain that every inch of that mineral must indicate many feet of crude vegetable matter." In a recent publication just to hand, Knowlton[128] states: "Recently a very important announcement has been made that, if fully substantiated, would go far to establish the presence of a land flora millions of years earlier than was previously supposed. Dr. R. Krausel, of Berlin, has described a small woody stem, from the pre-Cambrian rocks of Bohemia, to which he has given the name Archæoxylon, which signifies "ancient wood."

Since the greater part of evolution took place before the Cambrian and it is generally concluded that plant life must have developed before invertebrates, the assumption that land vegetation did exist in the pre-Cambrian may yet be fully substantiated. However, if land vegetation did not exist there is no doubt that

[120] Walcott, C. D., Smiths. Inst. Min. Coll., vol. 64, No. 2, 1914; Geol. Surv. of Canada, Mem. 28, p. 16, 1912.

[121] Moore, E. S., *Jour. Geol.*, 24, pp. 412–438, 1918; *Trans. Roy. Soc. Can.*, vol. 19, Sec. IV., p. 21, 1925.

[122] Grout, F. F., and Broderick, T. M., *Amer. Jour. Sci.*, 48, p. 199, 1919.

[123] Broderick, T. M., ECON. GEOL., 15, p. 422, 1920.

[124] Gruner, J. W., ECON. GEOL., 17, p. 418, 1922.

[125] Gill, J. E., ECON. GEOL., 22, p. 706, 1927.

[126] Grabau, A. W., "Comprehensive Geology," vol. 2, p. 289, 1920.

[127] Dawson, W., "The Geological History of Plants."

[128] Knowlton, F. H., "Plants of the Past," p. 44, 1927.

marine and fresh water plants did exist, and that they must have been exceptionally abundant to give the little evidence that is now preserved.

Conclusions Regarding the Origin of the Pre-Cambrian Banded Iron Formations.—From the results of the experimental work described in the first part of this paper and from a review of the literature dealing with the origin of the sedimentary iron formations, together with field experience, the following conclusions are drawn concerning the origin of the pre-Cambrian iron deposits. Assuming an abundance of organic matter in pre-Cambrian formations, it is possible for cold water to have extracted and transported sufficient iron and silica from the great areas of igneous rocks exposed in pre-Cambrian time to build up large deposits of banded iron and silica. The iron would be dissolved and carried as a ferric oxide hydrosol and the silica as colloidal silica, the two being stabilized by organic matter which kept them from mutually precipitating one another until thrown down by the electrolytes in the sea. The banding in the deposits, as shown by experiment, could be due to the differential rate of precipitation of the iron and silica combined with the influence of seasonal changes causing varying quantities of these substances to be brought into the basin of deposition at different periods throughout the year. The oölitic structure could be developed in the silica and iron muds on the sea bottom as they underwent consolidation. The lenses of silica, which are characteristic of the banded iron formations and which individually in most cases have no great lateral extent, are easily explained by observing the behavior of freshly deposited colloidal silica in the laboratory. Iron carbonate could be formed in the presence of abundant organic matter as it has been formed in the Coal Measures in many parts of the world but it could not be formed in cold solutions except when such organic matter was present.

The large quantities of fresh igneous rocks and especially the tuffs which are quite commonly associated with the pre-Cambrian banded iron formations could, under conditions of rapid weathering, supply much iron and silica to the streams. A great deal of

iron and silica solution might collect in local pools to be washed into the streams by heavy rains. If climatic and topographic conditions were favorable, a large proportion of these substances might be deposited in lakes or the sea with relatively little clastic sediment. That colloidal silica may be carried from siliceous tuff beds on a very large scale is well illustrated by some of the streams flowing from the beds of siliceous tuffs in the Cretaceous formations of Alberta and Saskatchewan. Further, the work of various investigators already cited indicates that some of the largest Palæozoic and Mesozoic sedimentary iron deposits, such as those of France, England, Newfoundland, and the eastern United States, have been formed by processes of sedimentation without the direct aid of magmatic waters. These processes of solution, transportation, and deposition apparently operated under special topographic and climatic conditions and possibly special conditions for the development of low forms of life. The great similarity between some of these iron formations and the Animikie formations of Minnesota, Ontario and the Hudson Bay region lead one to conclude that they might have formed in the same manner. These deposits are of wide extent and associated with ordinary sediments, just as the Palæozoic and Mesozoic formations are. They are all characteristically oölitic and the proportion of silica to iron in them is much less than it is in most of the older, highly banded formations of the Keewatin, which are much more restricted in size and much more numerous.

The senior writer has for years adhered to the idea that practically all the pre-Cambrian iron formations have been formed as the result of normal processes of weathering and chemical sedimentation. However, field work in recent years, followed by the laboratory experiments herein described, have led to a belief in Leith's contention that hot waters have played a more important rôle in the deposition of the highly siliceous formations associated with igneous rocks than was formerly admitted. A recent and more detailed study of the banded formations in the Lake Savant area, Ontario, has shown that there is much more igneous rock closely associated with the iron formations than a

previous reconnaissance survey had indicated. The detailed work by Collins in the Michipicoten area has led him to advocate a hot spring origin for the banded silica and a replacement origin for the carbonate and pyrite in that area. The writer's work on the Rush Lake section of the Woman River iron range,[129] where carbonate and pyrite also occur with banded silica, magnetite, hematite, and pyrrhotite, has led him to conclude that here also the carbonate and sulphides are replacement minerals. The great siderite deposits in the Cretaceous formations of Bilboa, Spain, are undoubtedly replacement deposits associated with igneous rocks, and Per Geijer [130] has recently advocated a similar origin for the iron carbonate deposits of Northern Africa. All through the pre-Cambrian areas of northern Ontario there are examples of extensive carbonization of rocks of different types through the action of heated carbonated water. In many places carbonization of igneous rocks has occurred to the extent of 70 or 80 per cent. of their volume.

The banding in the highly siliceous iron deposits is undoubtedly original and due to chemical deposition but it has apparently been accentuated by metamorphism. It may be observed in the field that up to a certain degree the more highly metamorphosed formations usually show, in comparison with others, a better developed banded structure. Possibly this is due to the fact that such rocks are more characteristic of the older pre-Cambrian formations, which are naturally more metamorphosed than the younger ones, but this does not explain it all. Replacement also may have emphasized the banding to some extent and been responsible for the addition of much silica to some deposits but no form of metamorphism can account entirely for the banded structure.

The conditions of formation of these banded formations must be peculiar to the pre-Cambrian era, since no deposits exactly similar have been formed in later eras although they were deposited on every continent in that era. The only thing approach-

[129] Ontario Dept. of Mines, 35th Ann. Rept., Pt. II., p. 86, 1926.
[130] ECON. GEOL., 22, p. 537, 1927.

ing such highly siliceous deposits forming to-day is found around hot springs and in association with igneous rocks. The results of laboratory work indicate how banding may be developed but they do not show anything which is adequate to explain the solution and transportation of such relatively large quantities of silica in cold waters. It seems necessary to invoke the direct aid of igneous activity on a large scale to account for the very siliceous chemical deposits. The other stratified iron deposits appear to be the result of normal sedimentary processes in which life has played an important part.

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AGAWA IRON FORMATION OF NORTHEASTERN MINNESOTA.[1]

J. T. STARK.

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INTRODUCTION.

It is also evident that no thoughtful person can ever again attempt to explain all deposits of iron ores on any one theory, because iron is a metal of such wide distribution and ready chemical affinity, and of such varied forms of combination that it may be acted upon by every agent of solution or decay as well as of precipitation or mechanical concentration.

THIS conclusion was reached by the Winchells in 1891,[2] after reviewing carefully eighteen different hypotheses which had been proposed to explain the accumulation of ferric oxide in massive deposits, such as occur in the Lake Superior region. Theories continue to multiply and no one appears applicable to all deposits. In suggesting a possible mechanical concentration as the origin for a part of one of the iron-bearing formations in the Lake Superior region, the writer wishes to make clear that such an origin is not intended to apply to other iron formations or even to all parts of the Agawa formation which occur in localities outside of the particular district here described. That the mechanical concentration may be unique to the area here discussed, and that

[1] Read by title before the Geological Society of America, New York, December 26, 1928.

[2] Winchell, N. H., and H. V., "The Iron Ores of Minnesota," Geol. and Nat. Hist. Surv. of Minnesota, Bull. 6, p. 254, 1891.

FIG. 1. Geologic map of Kekequabic Lake and vicinity, showing the distribution of the Agawa formation.

such an origin helps to explain the vertical range of the Agawa horizon, are believed to be sufficient justification for adding to the already long list of hypotheses to explain the origin of the Lake Superior ores.

The following is a report of progress. Although other outcrops of the Agawa formation have been visited and specimens collected, only those outcrops which occur in the vicinity of Kekequabic Lake have been studied in detail.

GENERAL GEOLOGY AND DISTRIBUTION.

The area here discussed is that of Kekequabic Lake near the northern edge of Lake County, and about two miles south of the Ontario-Minnesota boundary (Fig. 1). The formations consist of a basement of Keewatin greenstone, intruded by granodiorite and associated leucocratic and melanocratic dikes, which lie beneath an unbroken sequence of clastic sediments. These sediments, because of their stratigraphic succession and high degree of metamorphism, are believed to be Lower Huronian in age. No Laurentian intrusives are found in the immediate vicinity although they have suppied a large part of the constituents of the basal Huronian conglomerate. Contemporaneous with the deposition of the sediments intermittent volcanic eruptions occurred in the area, evidenced by tuffaceous members near the base and at the top of the Knife Lake slate series; and by intrusions of andesite which in some instances reached the surface.

The rock succession in this area is as follows:

QUATERNARY
- Recent lacustrine muds and sands.
- Pleistocene. Glacial drift (Wisconsin).

ALGONKIAN
- Keweenawan System
  - Diabase dikes.
  - Duluth gabbro.
- Huronian Igneous Rocks
  - Kekequabic granite.
  - Andesite.

Acid porphyries.
Huronian Sedimentary Rocks
Knife Lake series
Hornblende tuff.
Agglomerate.
Argillite.
Agawa iron-bearing formation.
Tuffaceous slate.
Tuffaceous graywacke.
Graywacke.
Ogishke conglomerate
Porphyry conglomerate.
Pebbly conglomerate.
ARCHEAN
Laurentian Series
Acidic and basic intrusions.
Cache Bay porphyry.
Frog Rock porphyry.
Saganaga granodiorite.
Keewatin Series
Acidic and basic intrusions.
Ely greenstone.

The Agawa iron-bearing formation occurs on the eastern part of the Vermilion district in Ontario and Minnesota. It consists of a series of discontinuous, banded lenses of ferruginous slates, varying in width from a few inches upward to two and three hundred feet. The formation occupies no exact stratigraphic horizon, but occurs in some places immediately above the Ogishke conglomerate and in other places well up into the Knife Lake slates which lie conformably above the Ogishke conglomerate. So far as known the Agawa formation possesses no economic value, the leanness of the iron bands and the limited thickness and extent of the lenses making it highly improbable that commercial development will ever be justified.

Outcrops of the Agawa formation are mapped in Ontario along the shores of This Mans, That Mans and The Other Mans

lakes which lie about two miles north of the Minnesota boundary, trending with the strike of the Huronian formations, slightly north of east. These outcrops are described by Clements [3] as consisting chiefly of "bands of chert, jasper, and iron oxides, with a carbonate-bearing chert and ferruginous slate in very subordinate quantity." Other outcrops in Ontario which have been mapped as Agawa on islands and at the end of a northeast bay in Carp Lake, lying between That Mans and Knife lakes, do not belong to the Huronian, but are clearly areas of the Soudan iron formation surrounded by and occurring as down folds in the Archean greenstone.

In Minnesota the Agawa is well exposed on hills between Moose and Wind lakes, sec. 20 and 21, T. 64 N., R. 9 W., and in several outcrops in the vicinity of Kekequabic Lake, T. 64 N., R. 6 and 7 W.. These two areas are correlated by Clements and described as interbedded slates and jasper bands, essentially the same as the Ontario outcrops.[4] The Agawa horizon is suggested by ferruginous bands in the Knife Lake slates between Snowbank and Disappointment lakes, sec. 32, T. 32 N., R. 8 W., and Professor J. W. Gruner pointed out to the writer last summer newly discovered areas of well banded iron formation surrounded by the Knife Lake slates south of Grout Lake, sec. 34, T. 66 N., R 6 W. Doubtless many similar outcrops of the Agawa horizon will be discovered as detailed mapping in the region is continued.

In the above table of formations the graywacke, tuffaceous graywacke and tuffaceous slate show commonly horizontal gradations and all are not always in every section. Where accumulations of hematite and magnetite deposits are of sufficient concentration in the tuffaceous slate to be called an iron-bearing formation, they occur between the typical argillite and the coarser tuffs below. The iron bands are not continuous but pinch out along their strike. In common with the other Huronian sediments they have been steeply folded into anticlines and synclines,

[3] Clements, J. M., "The Vermilion Iron-bearing District of Minnesota," U. S. Geol. Surv. Mon. 45, p. 325, 1903.

[4] Idem, p. 325.

with a regional strike slightly north of east and at angles that approach vertical. In places the folds are slightly overturned to the north. The best exposures of the iron beds occur in narrow belts along the flanks of an anticline north of Kekequabic Lake, extending through sections 25, 26, 35 and 36, T. 65 N., R. 7 W. Isolated outcrops due to small folds occur in the center of section 4, T. 64 N., R. 7 W., and in the NE. ¼ section 32, T. 65 N., R. 6 W. None of the belts is more than a few hundred feet wide and most of them are much less, the width of outcrops being in many cases increased due to repeated minor folding. In some exposures the widths are only a foot or two.

All exposures of the iron-bearing formation are characterized by drag folding, distortion and faulting. The folds are commonly close, and the well-developed drags afford valuable aid in working out the larger structures.

PETROGRAPHIC DESCRIPTION.

The following description refers only to the Kekequabic area.

The rock of the Agawa iron formation is composed of dark red, jasper-like hematite bands ranging from the thinness of paper to several inches in thickness. The hematite is a duller red than the typical Soudan jasper and is interbedded with dark gray to dark green tuffaceous slate. The tuffaceous beds are composed of fine and coarse bands which weather characteristically to a light, whitish gray, and these bands, alternating with the real hematite, give a typical banded appearance to the outcrops. Quartz veins commonly cut the iron-bearing formation, but interbedded chert and jasper, which are such prominent features of the jaspilite in other parts of the Lake Superior region, are not found in any of the Kekequabic Agawa deposits.

Typical sections under the microscope show the iron bands to be concentrations of very fine hematite and larger crystals of magnetite interbedded with, and grading into, fragmental tuffs. The tuffs underlying the iron bands are composed largely of mineral fragments in a groundmass of fibrous hornblende and they contain larger particles of amphibole crystals (crystal tuff), or they

are composed predominantly of fragments of andesite in which phenocrysts of amphibole and feldspar are similar to the finer particles of the groundmass (lithic tuff). Recrystallization has occurred in all the beds and the mortar textures so typical of pre-Cambrian tuffs are well developed.[5] The clastic character of the tuffaceous beds of the iron formation is clear in many of the coarser bands which show the texture and composition of the crystal and lithic tuffs.

In the tuffaceous bands interbedded with the iron lenses the fragments are predominantly of sharp angular quartz, feldspar, amphibole and andesite rock with a very small amount of a fine grained acid porphyry. In the coarser bands the quartz is usually more abundant than the feldspar; the latter is relatively scarce as a fragmental constituent and when present is always highly epidotized and chloritized; extinction angles indicate a basic oligoclase. Occasional pseudomorphs of pennine show the outline of hornblende fragments. Centers of these grains contain areas of pale green amphibole, possibly the result of bleaching of the original, associated with granular calcite and magnetite. The rock fragments are usually of fine grained andesite, some aphanitic and non-porphyritic, but more commonly showing numerous small and large phenocrysts. They always carry small particles of ferrite which are thought to be hematite. In reflected light the entire surfaces of the fragments have a red color due to the dissemination of these small particles throughout the rock. The andesite fragments average 1 to 1.5 mm. in diameter in the coarser bands but are commonly much smaller and grade into the finest material of the groundmass.

Recrystallization in the groundmass has resulted in a cloudy mass of quartz, clear feldspar (probably albite), with much opaque material in which numerous microlites of chlorite, epidote, pyroxene, zoisite and actinolite-like needles are closely crowded. Epidote in the form of pistachite becomes prominent in some

[5] Morris, T. O., and Fearnsides, W. G., "The Stratigraphy and Structure of the Slate Belt of Nantlle (Carnarvonshire)," *Quart. Jour. Geol. Soc.*, vol. 32, pp. 286–288, 1926.

bands, and occurs in scattered grains, aggregates and veinlets. The finest particles of ferrite which cloud the groundmass give the reddish tint of hematite and appear identical with the hematite in the rock fragments of the andesite. Crystals of hematite are scattered through the tuffs in amounts proportionate to the finer hematite concentrations. The iron bands appear merely as very fine fragmental material in which there is a greater concentration of hematite and magnetite. Recrystallization is more intensive in the finer deposits. Edges of the quartz fragments are in places fused with the groundmass though still revealing their original sharply angular character. Considerable contemporaneous crystallization of the chlorite and quartz has occurred. Darker portions of the iron bands are formed by the close crowding together of the small crystals of magnetite and hematite particles. The larger crystals are about .5 mm. in diameter and from this size range down to the finest particles, indistinguishable from the hematite. These magnetite octahedra are clearly metacrysts formed by dynamometamorphism of a ferruginous tuff.

Approximate averages of the iron-rich and iron-poor bands of the Agawa rocks show:

	Iron rich per cent.	Iron poor per cent.
Magnetite	43	9
Hematite	31	2
Quartz	12	25
Chlorite	5	50
Feldspar	8	10
Epidote	1	4
	100	100

There is no mistaking the clastic character of the bedded sedimentary iron-bearing formation whatever may be the origin of the iron bands. The position of the tuffaceous slates which contain the iron bands has been stated above. The concentrations of the hematite and magnetite are greatest in the finer sediments, indicating greater assortment and transportation than in the underlying and interbedded tuffs.

ORIGIN OF THE IRON BANDS.

Before discussing the probable origin of the iron bands, the distinctive features of the Agawa formation are reviewed in the following summary:

Summary.—1. Lens-like tuffaceous beds, rarely more than 100 feet thick and more commonly from a few feet to a few inches, occur near the base of the Knife Lake slates and contain thin bands of the iron minerals hematite and magnetite.

2. The enclosing beds vary from lithic tuffs in which the andesite is the prominent constituent to finer slate and graywacke-like facies with numerous fragments of hornblende, quartz and feldspar embedded in a debris of andesitic rock and minerals.

3. The andesitic fragments as well as the recrystallized groundmass contain particles of hematite, scarcely distinguishable in individual grains, but in aggregate giving a characteristic red color to the sections in reflected light. Associated with the hematite of the groundmass are many small octahedral crystals of magnetite which do not occur in the andesite fragments, but appear to have originated from the recrystallization of the iron in the groundmass.

4. The banded appearance of the iron formation, resembling typical jaspilite, is due to weathering of the fine tuffaceous slate between the darker bands of hematite and magnetite to a light ash color, and not to any bands of chalcedonic silica nor to bands of cherty iron silicate or carbonate which makes so many of the light-colored bands in other formations of the Lake Superior region. Many quartz veins cut the iron formation, but these are true filled veins and are distinctly later than the formation of the iron bands.

5. The iron bands consist of concentrations of very small particles of hematite and larger crystals of magnetite held in a fine tuffaceous debris which shows progressive gradation below and above into coarse lithic and crystal tuffs. Where concentration of the iron minerals is greatest the amount of hornblende and feldspar is correspondingly small; in coarser tuffs, on the other hand, there is abundant hornblende and feldspar, with the iron

minerals disseminated throughout without any appreciable concentration.

6. No evidence of greenalite nor of cherty iron carbonate as a chemical precipitate at the time of formation of the beds was found. Carbonate is present in small amounts but appears as a secondary, finely granular alteration product of hornblende and feldspar, which form a conspicuous part of the fragmental tuffs.

7. The hematite particles show very little variation in size and usually appear as small dots disseminated throughout the sections. The magnetite occurs in small crystals, usually showing octahedral sections, and varies from 1 mm. in diameter to extremely small grains. Under the highest objective even the smallest grains seem to have crystal outlines.

8. In the densest concentrations of the iron bands the clastic nature of the bed is made apparent by the angular quartz and feldspar fragments.

9. The hematite occurring disseminated throughout the massive andesite formation is similar in appearance to the hematite particles in the andesite fragments of the tuff and to the hematite particles in the concentrated lenses of the iron bands. The amount of hematite varies in the massive andesite; in the andesite fragments of the tuffs adjacent to the iron bands, the hematite content is greater than the average but no greater than it is in much of the massive andesite.

Igneous Associations.—A relationship between the origin of the iron bands and the vulcanism is strongly suggested by the close association with the volcanic clastics. Of the various hypotheses which have been suggested for the origin of the Lake Superior iron formations three which have to do with contemporaneous vulcanism are briefly reviewed.

In 1891 N. H. and H. V. Winchell suggested a possible origin of the Keewatin iron deposits. Hot alkaline waters are assumed to have acted readily upon volcanic ejectamenta. The silicates were partly decomposed and insoluble residue mixed as a siliceous pulp with other grains that were not decomposed.

When the supply of material was rapid from the subterranean sources, this decomposition was not completed and the sediments were simply distributed by currents and waves as sand and clay are now, retaining largely their chemical composition and sometimes their mineral structures. More or less change was effected in nearly all cases and augitic and feldspathic and olivinitic minerals were reduced by decotive action of water to chloride and micaceous elements . . . with a continual supply of basic rocks coming continually in contact with heated alkaline waters, chemical action ensued to cause the precipitation of the iron among the accumulating sediments at the bottom of the sea.[6]

In 1900 N. H. Winchell suggested that the iron-bearing formation of the Vermilion district was first deposited as a ferric oxide and that the ferruginous cherts making up the greater part of the formation today were original oceanic deposits laid down essentially in their present form.[7]

Van Hise and Leith presented the hypothesis that the iron was brought to the surface by igneous rocks and contributed either directly by hot magmatic waters to the ocean or later brought by surface waters under weathering to the ocean, or other body of water, or by both, and from the ocean deposited in ordinary succession of sedimentary rocks.[8]

W. H. Collins concludes that for the Michipicoten iron formation mineralized water was the chemical agent affecting the carbonate replacement and that the field evidence strongly suggests an igneous source for the solutions which deposited the iron and associated minerals. Banded silica is a constant associate with the sideritic bands and both are thought to have been formed by the same chemical agent.[9]

Origin of Agawa Formation.—In each of the foregoing hypotheses the vulcanism is assumed to precede or to be contemporaneous with the deposition of the iron. In the Kekequabic

[6] Winchell, N. H., and H. V., "The Iron Ores of Minnesota," Geol. and Nat. Hist. Surv. of Minnesota Bull. 6, pp. 105–112, and 213–256, 1891.

[7] Winchell, N. H., "The Geology of Minnesota," vol. 5, pp. 997–998, 1900.

[8] Van Hise, C. R., and Leith, C. K., "The Geology of the Lake Superior Region," U. S. Geol. Surv. Mon. LII., pp. 518, 527, 568, 1911.

[9] Collins, W. H., and Quirke, T. T., "Michipicoten Iron Ranges," Canada Geol. Surv. Mem. 147, p. 73, 1926.

area the iron is contained in volcanic tuffs that are composed of fragments of silicates and of quartz, and of rock fragments partly decomposed. So far this is in agreement with the early theories of the Winchells. However, if the "selective and ever active forces," which they assume extracted iron and silica from overcharged oceanic waters and formed a chemically pure product, were at work in the sea of the Kekequabic area, no record of their action is left in the present iron deposits, such, for example, as the presence of chalcedonic quartz. Furthermore, the above writers state that the variation in jaspilite, whether in color or in composition, is due solely to the relative proportions of silica and hematite.[10] In the Agawa formation the iron bands are by no means a chemically pure product, but instead they are decidedly an impure clastic sediment.

Although it is entirely possible that chemically precipitated silica, greenalite and cherty iron carbonate may have been originally present in the Kekequabic area as suggested by Van Hise and Leith and later have been removed, the absence of any trace of these minerals in the Agawa formation here, and their abundance in so many of the ferruginous slates of the Lake Superior region which have undergone metamorphism as severe or even greater than that to which the iron formation at Kekequabic Lake was subjected, make it seem highly improbable that they were ever deposited.

Positive evidence is lacking of replacement such as is recognized by Collins in the Michipicoten area. Carbonate is present in small amounts in the enclosing tuffs, but it has always the appearance of being a secondary alteration after amphibole and feldspar. It does occur prominently in the Ogishke conglomerate and forms a conspicuous zone of carbonate rock between the conglomerate and the coarse graywacke of Ogishkemuncie Lake, several miles east of the Kekequabic area. This is considered as a later replacement and not original bedding by members of the Minnesota survey,[11] but assuming it to represent a stratigraphic

[10] Winchell, N. H., and H. V., "The Iron Ores of Minnesota," Geol. and Nat. Hist. Surv. of Minnesota Bull. 6, p. 254, 1891.

[11] Personal communication with F. F. Grout and J. W. Gruner.

horizon one might expect to find traces of it in the Kekequabic Agawa lenses had it played any important role either at the time of the iron deposition or later.

From field and microscopic study of the iron lenses in the Kekequabic area, the writer believes that the concentration may have been accomplished mechanically without the aid of chemical precipitation. In thin sections there is always a suggestion that mechanical concentration may have been responsible for the banding. It seems possible that there occurred a concentration of the ferruginous debris due to (1) the heavier specific gravity of the iron-rich particles, and (2) the floating and leaching of the lighter and more readily soluble feldspar and hornblende, leaving behind an iron-rich quartose residue. It is hardly conceivable that the andesite could have been so finely fragmented as to release the very small particles of hematite and magnetite, and in the iron bands this does not seem to have happened, for even in the densest concentrations there is always a more or less cloudy debris separating the heavier particles. It is more probable that certain portions of the andesite magma were richer in iron content than others, and that since the fine debris of the iron-rich tuff was heavier, it was amenable to a mechanical concentration.

The Huronian sea was probably agitated by intermittent explosive volcanic ejections, as shown by the series of tuffaceous sediments, but the finely assorted nature of the iron lenses indicates quiescent periods of some length between the explosive ejections. Current and wave action is recorded in the cross bedding of the tuffs and the iron-rich tuff was undoubtedly subjected to shifting currents. Under these conditions the lighter particles would be carried away and the iron-rich particles concentrated. With renewals of rapid additions to the sea of volcanic material, the iron-rich beds were soon covered by coarser tuffs. In these coarse tuffs the hematite and magnetite particles were more or less evenly distributed and represent the normal iron content of the volcanic material with only a minimum amount of concentration.

CONCLUSION.

The definite clastic nature of the deposits and the evidence of some mechanical concentration are reasonably established. Whether this was great enough to account for all the concentration of the iron bands may be questionable. Considering the Kekequabic area only, it is believed that gravity, flotation, and subsequent leaching may have been the only concentrating agents; and this conclusion is based on the fragmental character of the iron bands, the iron-rich particles of the andesite in the enclosing tuffs, the progressive gradations from the tuffs to the lenses rich in iron, and the inverse relationship between the amount of hornblende and feldspar to the richness of the iron.

It is not intended to suggest that such an origin as mechanical concentration applies to other iron formations, or even to the Agawa formation in localities outside of the Kekequabic area. So far as the writer is aware, no similar iron-bearing beds have been described in the Lake Superior region.

The writer desires to make special acknowledgment of the help and interest of Professor U. S. Grant, of Northwestern University, under whose guidance the field work was carried out; and to Professors Albert Johannsen and R. T. Chamberlin, of the University of Chicago, for helpful suggestions and criticisms during the laboratory study and preparation of part of the report.

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DISCUSSION AND INFORMAL COMMUNICATIONS

THE ORIGIN OF ARTESIAN PRESSURE.

Sir:—In a recent issue of ECONOMIC GEOLOGY, Piper [1] criticised the writer's paper [2] on "The Origin of Artesian Pressure." Some of Piper's criticisms are plausible and pertinent, and seem at first sight to constitute serious objections to the theory. However, when critically examined, many of Piper's objections are found to be invalid, and the remainder are seen to be based on misunderstandings of the writer's paper.

Before proceeding to consider Piper's objections in detail, it may be well to restate the theory briefly. In the original paper,[3] the writer suggested that the water of certain artesian areas may not be meteoric water entering from the outcrops, but may be connate water more or less diluted or replaced by water expelled from associated formations, and that the chemical differences in the waters are due partly to the chemical characteristics of the original cognate waters, and partly to the chemical nature of the water that has since been added. This theory is a general one, intended to apply to all areas where the aquifer lies in disconnected sheets or lenses. The pressure is explained as being due to the compression and compaction of the water-bearing sandstones by the weight of the overburden. In the original paper the writer attempted to show that the Dakota artesian basin was such an area, and that the compression-compaction theory could be applied to it. In his discussion of the paper, Piper tries to show that the theory could not be applied to the Dakota artesian area, but does not attempt to disprove the general theory.

[1] Piper, A. M., ECON. GEOL., vol. 23, pp. 683–696, 1928.
[2] Russell, W. L., ECON. GEOL., vol. 23, pp. 132–157, 1928.
[3] Russell, W. L., *idem*, pp. 151–156.

The Conventional Sections.—Piper[4] begins his discussion by introducing the conventional sections in the Black Hills region and the eastern side of the basin. Entirely aside from the correlation of the so-called Dakota sandstones on the two sides of the basin, it is certain that these conventional sections give a false idea of the relations, and that their general acceptance has been largely responsible for the misconceptions regarding the stratigraphy and artesian conditions in this region. Since Piper accepts these conventional sections, it is not surprising that he holds to the old theory of artesian circulation. The sections introduced by Piper[5] show the sandstones as simple and regular formations like those of textbook illustrations, whereas their actual character is just the opposite. In the Black Hills region the Newcastle sandstone on the east side of the Black Hills is not persistent as shown, but consists of scattered lenses, and along two-thirds or three-fourths of the outcrop there is no sandstone at all, or only an exceedingly thin or shaley layer of sandstone. Moreover, there are sandstones at several horizons in the Graneros shale, as stated elsewhere.[6] The Dakota and Lakota sandstones are not regular sandstones with no shale, as shown in the section cited by Piper, but are generally broken up into a series of sandstones separated by shale or clay. Moreover, what is called the Fuson shale is probably not everywhere at the same horizon, and there are shales as thick as the Fuson shale in places in the Lakota formation. In the eastern side of the basin the Dakota sandstones consist of a series of sand lenses separated by shales and clays, with the sandstones occupying only one-third or one-fourth of the bulk of the formation.

These facts were established by the writer by measuring a large number of detailed sections through the outcrops of the formations at frequent intervals. In the exposures of the Dakota and Lakota formations on the east and west sides of the basin the sandstone members are relatively hard and form prominent

[4] Piper, A. M., *op. cit.*, p. 684.

[5] Piper, A. M., *idem*, p. 684.

[6] Russell, W. L., "The Origin of the Sandstone Dikes of the Black Hills Region," *Amer. Jour. Sci.*, vol. XIV, 1928, pp. 403, 404.

ledges, whereas the softer shales and clays form slopes and may be revealed only by careful search. Moreover, in the Black Hills region the Dakota and Lakota formations in a few places consist chiefly of sandstone. Where this is the case they are hard and resistant, consequently geologists seeing the sandstone cliffs are likely to conclude that the whole formation is everywhere sandstone. This is doubtless the origin of the errors contained in the conventional section.

The Correlation and Lenticularity of the "Dakota."—It should be understood that the data given in the writer's paper [7] represent only a brief summary of the evidence. The facts are stated much more fully in the complete bulletin.[8] Unfortunately, the publication of this bulletin has been held up by the vetoing of the Survey appropriation.

In the original publication [9] the writer stated that the so-called Dakota sandstone of the Black Hills region is older than the type Dakota on the east side of the basin. Piper [10] attempts to discredit this correlation by showing that the Newcastle sandstone contains in one place a pre-Dakota Cheyenne flora, and in others a true Dakota flora. In support of this he quotes Berry to the effect that the flora of the so-called Newcastle sandstone at Hermosa, South Dakota, is of Dakota age. In a personal communication Berry [11] stated that Piper obtained his data from an unpublished manuscript in the possession of the U. S. Geological Survey. In the same letter Berry makes the following statement:

> On looking up my manuscript I find that the only Dakota I recognized paleobotanically, and that not very conclusively, was a collection made by Dr. Stanton from the Graneros at a locality two miles northwest of Hermosa. A collection by Rubey from the supposed Dakota at the classic Black Hills locality for Dakota at Evans Quarry turned out to

[7] Russell, W. L., ECON. GEOL., vol. 23, pp. 132–157, 1928.

[8] Russell, W. L., "Stratigraphy and Structures in Western South Dakota," So. Dakota Geol. and Nat. Hist. Surv. Bull. 13.

[9] Russell, W. L., ECON. GEOL., vol. 23, pp. 132–157, 1928.

[10] Piper, A. M., *op. cit.*, p. 686.

[11] Berry, E. W., Personal communication, Nov. 28, 1928.

be not Dakota but older. From what I gather from the plants I have seen, and from conversation with Dr. Reeside, I much doubt the continuity of any of the sandstones in the Black Hills region.

The statement that the Evans Quarry sandstone is older than the Dakota, which Piper failed to quote from the manuscript, is in strong support of the writer's correlation. In the lower part of the Graneros shale in the Black Hills region there are sandstone lenses at several horizons, as stated elsewhere.[12] As these are far from continuous, it is difficult to correlate sandstones in different parts of the Black Hills region. If the flora collected near Hermosa is Dakota, it simply means that this sandstone is not the same as the sandstone from which the writer collected the flora pronounced by Berry of pre-Dakota Cheyenne age. There is thus no reason to suppose that the Newcastle contains two floras.

The Origin of the "Salty" Waters.—Piper[13] also objects to the writer's suggestion[14] that some of the salt water in the Dakota has been derived from the Graneros shale, on the ground that the water could not move into deeper strata. This suggestion is not a necessary or important part of the theory, as Piper seems to suppose, but is merely a possible explanation of the salty character of the water in the uppermost sandstone. It is possible, as previously stated,[15] that the salty waters are cognate waters, more or less diluted with fresh waters expelled from the underlying beds in their compaction. Since the sandstones may interfinger with marine Graneros shale towards the west, it is also possible that the salt was forced out of a stratum of the Graneros shale below the uppermost sandstone.

It is also not impossible that the small quantities of salt in question could in certain cases have been derived from the overlying shales. It is true that the general course of the waters across the strata should be upward, but in the region in which

[12] Russell, W. L., "The Origin of the Sandstone Dikes of the Black Hills Region," *Amer. Jour. Sci.*, vol. XIV, pp. 403, 404, 1928.

[13] Piper, A. M., *op. cit.*, pp. 688–689.

[14] Russell, W. L., ECON. GEOL., vol. 23, pp. 151–152, 1928.

[15] *Idem*, pp. 151–152.

the salty waters occur the strata have been faulted and folded. During the folding the shales a few feet above the sandstone may have been locally under slightly greater pressure than the sandstone. Hence, waters squeezed from them might have entered the sandstone and displaced the waters in the sandstone along the line of least resistance. The faults may have been avenues for the escape of the waters driven from the shales and sandstones during compaction, in which case these waters would tend to flow from the overlying shales into the adjacent sandstone, and along the sandstone to the faults. Faults or fractures may have been opened in the shales, and salt water escaped from the shales into the fractures and from the fractures into the sandstone. Wells drilled for water in western and central South Dakota sometimes encounter salty water in the Benton shales, and this water must be in fractures. Finally, small quantities of salt may have reached the sandstone by diffusion from the overlying shales. In a recent paper Whitman [16] shows that diffusion may take place through the pores of rocks as dense as marble, and also states that substances may diffuse through considerable distances during geologic time. Diffusion could presumably take place much more readily through clays and shales like those associated with the Dakota than through a dense rock like marble.

The Dilution of the Waters.—Piper [17] also objects to the compression-compaction theory on the ground that all the waters are much less concentrated than sea water, and that the artesian waters are not characteristic of a marine, brackish water or continental environment. It is certainly true that the artesian waters, even the "salty waters" in the northwestern part of South Dakota, are much less concentrated than sea water. This may be explained by the assumption that they were originally cognate fresh waters, and that the small quantity of salt was added later, as previously explained. However, the mode of deposition of the aquifer suggests that certain parts of it would be laid

[16] Whitman, A. R., Diffusion in Ore Genesis, ECON. GEOL., vol. 23, pp. 437–488, 1928.

[17] Piper, A. M., *op. cit.*, pp. 690–691.

down in salt or brackish water. We do not know the concentration of the water in the Cretaceous epeiric sea in this locality, but it may be inferred that it was much more concentrated than the salty waters. This dilution may be ascribed to the upward percolation of fresh waters derived from the underlying continental deposits during their compaction. It is known that sands containing fresh water under high pressure underlie the aquifers in the west-central or western part of the state, and it is possible that these waters have percolated upwards as far as the Dakota sandstones in certain places. The composition of the fresh waters now obtained from the Dakota sandstones is what would be expected in cognate fresh waters that had been modified by the addition of waters expelled from the underlying shales, and by the solution of various substances in the associated and underlying formations. Though sufficient information is not available to determine the exact manner in which the salt waters that may have been present have become diluted, the processes just described are capable of producing any dilution that has occurred, and this dilution is no reason for rejecting the compression-compaction theory. On the other hand, the known variations in the chemical composition cannot be explained by the old artesian theory.

The Belt of "Salty" Waters.—The belt of salty waters with gas which covers a great area in northwestern and west-central South Dakota, and probably extends into south-central North Dakota, is the most convincing evidence against the artesian theory. For this reason Piper's efforts to explain away this difficulty should be carefully analyzed. Piper[18] suggests that the fresh waters east of the belt of salty water have flowed around its south end, and that the salty water has remained in the bottom of the regional syncline because of its greater specific gravity. Both of these hypotheses may easily be shown to be impossible. The eastern edge of the belt of salt water, as indicated by Fig. 1 of the writer's original paper[19] extends in a north-south direction

[18] Piper, A. M., *idem.*

[19] Russell, W. L., ECON. GEOL., vol. 23, p. 141.

for a distance of over 100 miles in South Dakota, and probably continues for a considerable distance in North Dakota. Since the eastern edge of the belt of salty water is approximately parallel to the isopiestic lines or contour lines of head, the fresh waters just east of the northern part of the belt would, according to Piper's hypothesis, have to flow nearly parallel to the isopiestic lines all the way from the southern end of the belt. This is clearly impossible, for the proven principles of artesian circulation require that the flow shall be in general at right angles to the isopiestic lines. It is conceivable that the waters might flow parallel to the general course of these lines for a short distance while following a tortuous course, but they certainly do not defy the laws of physics and flow parallel to the isopiestic lines for over one hundred miles.

When the quantitative effects of the various factors are determined, it becomes evident that the influence of the greater specific gravity of the salty waters is negligible. If the aquifer is continuously permeable, as Piper supposes, the greater artesian head of the water on the west would tend to force the belt of salty waters eastward. As the salty water was forced up the east limb of the regional syncline, its greater specific gravity would create a force opposing the artesian flow. The magnitude of this force may be calculated by determining the difference in the weight of the columns of water on the two sides of the syncline. As the salty water is much more dilute than sea water, its specific gravity is probably no more than half of one per cent. greater than the specific gravity of the fresh water. The dip up the east limb of the regional syncline is probably no greater than 300 feet in 50 miles. The increase in the altitude of head toward the west is at an average rate of four feet per mile. Hence, the force tending to drive the waters eastward would be equivalent to about 200 feet head of water. Since the column of water 300 feet high on the east side of the syncline weighs one-half of one per cent more than the column of water on the west side of the syncline, the maximum force opposing the movement of the water would be only one and a half feet of head. In other words,

the force driving the waters east amounts to 200 feet head, and the opposing force one and one-half feet of head, or less than one per cent as much. It is obvious, therefore, that the greater specific gravity of the water would not have any appreciable effect, and that it can safely be neglected. The belt of salty water thus remains an unanswerable argument against artesian circulation.

The Relation of the Artesian Pressures to the Outcrops.—Piper [20] also says that

> In discussing the variations in the artesian pressure in the Dakota basin, Russell sets up two fundamental relations: First, the lines of equal head or pressure as mapped by Darton do not curve around those areas in which the Dakota crops out in the Black Hills and in the eastern part of South Dakota. . . . Nevertheless, it can be stated without reservation that the lines of equal head most emphatically do curve around the areas of outcrops both in the Black Hills and eastern Dakota. . . . Russell's denial of these relations is quite unwarranted.

The writer made no such statement as that just quoted. The contour lines of head obviously do curve around the area of outcrop in the Black Hills region, as they would be expected to do according to both theories. What was stated was that the effect of the Black Hills is not perceptible in the course contour lines of head in central North and South Dakota, which is entirely different. The actual statement was as follows:[21]

> If the water came from the Black Hills, the lines of equal head should curve around them to some extent, and this should be apparent even in eastern North Dakota, South Dakota and Nebraska. However, nothing of this nature may be detected in Darton's map. Furthermore, if the old hydraulic theory is correct, the lines of equal head should also curve around the areas where the sandstone outcrops at a low level, as, for example, in the southeastern corner of South Dakota, while the head should be greater where the sandstone thins out and disappears against the pre-Cambrian rocks, without outcropping towards the east. As a matter of fact, however, the map shows no particular influence of the nature of the eastern termination of the sandstone.

The conditions shown by Darton's map are exactly as stated in the above quotation.

[20] *Op. cit.*, pp. 691–692.

[21] Russell, W. L., *op. cit.*, pp. 141–142.

As the statements made by the writer [22] regarding the relation between the head and the outcrops of the aquifers have evidently been misunderstood by Piper, it seems advisable to explain what was meant in more detail. The outcrops in the Black Hills are much further east than the outcrops in the Rocky Mountain Front Range, and this is especially true on the north. The laws of artesian flow require that the contour lines of head should bend to the east in central South Dakota in the area east of the Black Hills, and should bend to the westward again in the area northeast of the Black Hills. Darton's map,[23] however, shows these lines running in a nearly straight general course from Kansas across Nebraska and South Dakota into North Dakota. This is what would be expected if the difference in head was due to regional tilting and uplift, but not what would be expected if it was due to artesian circulation.

If the apparent hydraulic gradient is due to true artesian circulation, this gradient should not be affected by the general elevation of the surface between the outcrops. If, on the other hand, it is due to differential uplift, the apparent hydraulic gradient should be steeper where the general slope of the great plains is steeper, and gentler on the east where the plains slope at a lesser angle. Darton's maps, [24] show that the apparent hydraulic gradient is steeper where the general slope is steeper, and gentler in the eastern portion of the basin where the general slope of the surface is gentler. For example, in Meade County, S. D., about 20 miles east of Piedmont, the general elevation of the surface is about 3,000 feet and the altitude of the head according to Darton's [25] map is 3,000 feet. At a point about 100 miles east of this and 10 miles west of Wendte the general elevation of the surface is about 2,000 feet and the altitude of the head 2,070 feet. The apparent hydraulic gradient is therefore 9.3 feet per mile, and the slope of the surface is 10 feet per mile. In western

[22] Russell, W. L., *op. cit.*, pp. 141, 142.

[23] Darton, N. H., U. S. Geol. Surv. Prof. Paper No. 32, plate LIX.

[24] Darton, N. H., U. S. Geol. Surv. Prof. Paper 32, Water Supply Paper 227, plates.

[25] Darton, N. H., *op. cit.*

Minnesota 230 miles east and a little north of this last point and 10 miles east-southeast of Gary, S. D., the general elevation of the surface is 1,250 feet and the altitude of the head is 1,200 feet. The apparent hydraulic gradient in this eastern part of the basin is therefore only 3.6 feet per mile and the surface gradient is 3.2 feet per mile.

The evidence furnished by the relation between the altitude of the head and the eastern outcrops of the Dakota sandstone is even more striking. In the extreme southeastern corner of South Dakota and for a great distance to the south the Dakota sandstones outcrop in a broad belt. North of this point in South Dakota and southeastern North Dakota the Dakota sandstones disappear by overlap against the pre-Cambrian crystalline rocks, and do not outcrop at all. As Darton's map[26] shows, the Benton shales and the Niobrara formation rest on the crystallines where they emerge. There are also no outcrops of the Dakota sandstones on the ridge of crystalline rocks which extends for about 60 miles west from Sioux Falls. If the artesian pressures are due to hydraulic circulation it is to be expected that the relations would be different where the Dakota sandstones outcrop and where they disappear without outcropping. As a matter of fact the relations appear to be the same whether the sandstone outcrops or does not. This may be readily explained according to the compression-compaction theory, for the thickness of the overlying rocks grows progressively greater away from the outcrops of the sandstones, and away from the areas of crystalline rocks where the sandstones do not outcrop. This relation cannot be explained by the hydraulic theory unless the waters can percolate along the unconformity between the pre-Cambrian and the Cretaceous. There is no evidence that this is possible, and in one place there is definite evidence that there is no such percolation. In Turner county, S. D., the 1,200 feet contour line of head is shown on Darton's map[27] extending in a northwesterly direction roughly parallel to the neighboring Cretaceous-pre-Cambrian contact. The altitude

[26] Darton, N. H., *op. cit.*

[27] Darton, N. H., U. S. Geol. Surv. Water Supply Paper 227, plates.

of the head along the contact would therefore be less than 1,200 feet, whereas the elevation of the surface as indicated on the same map is between 1,250 and 1,500 feet. It would obviously be impossible for the waters to flow to the surface along the unconformity, for its outcrop is considerably higher than the altitude of head of the waters. The decrease in the altitude of the head towards the areas of crystalline rocks can scarcely be explained by assuming that more water was withdrawn closer to them, for in some cases, as in Turner county, there is a belt close to the pre-Cambrian in which the waters will not flow, while further away, where the altitude of head is greater, flowing wells are obtained. The artesian wells are generally much more numerous and the amount of water produced by each well much greater where the waters will flow than where it will not flow and has to be pumped.

The Relation of the Artesian Pressures to Depth.—Piper [28] also argues that according to the compression-compaction theory the pressure of the water should increase directly with the depth, and that consequently the greatest pressures should be found in the northwestern part of the state, whereas this is not the case. This introduces a complicated problem, about which very little is known. If depth were the only factor affecting the pressure, then certainly the pressure should be proportional to the depth. As a matter of fact, however, there are a host of other factors and conditions which may affect the resultant pressure. Among these may be mentioned the degree of cementation of the sandstone, the sizes, shapes and sorting of the grains, the presence of shaley or micaceous impurities, the effect of water absorbed or expelled from adjacent formations, the influence of faulting and folding, and the effect of erosion. Since these factors would tend to be approximately equal in the same formation in the same locality, it may be supposed that the pressures on the water in sandstone lenses in the same formation in the same locality should increase with depth. This is exactly what is found in the Dakota artesian basin in eastern and central North and South Dakota. The head of the waters in the lower sandstones of the "Dakota"

[28] *Op. cit.*, 694.

series is greater than that of the upper sandstones. This is all the agreement between the head at the surface and the depth that is to be expected under the compression-compaction theory.

As stated in the writer's original paper,[29] there are many regions in which the head of the water in the sandstones is not sufficient to produce flowing wells, even though the sandstones are in disconnected lenses and buried to considerable depths. Between eastern and western South Dakota there is a gradual change from a region of flowing wells to a region in which the wells will not flow. Many causes may have brought this about, but it is possible that the effect of deformation or erosion is the dominant factor. When sandstones are subjected to pressure they contract and on the release of pressure they expand again. It is possible that shales behave in the same manner. In the western part of South Dakota there has been much more deformation than in the eastern part, and the amount of erosion has also been much greater. Eastern South Dakota consists of a comparatively flat plain, which has apparently been but little eroded. Western South Dakota, on the other hand, has been uplifted and eroded, as is shown by the depth of the valleys and the comparatively large amount of relief. Moreover, the thickness of late Cretaceous formations removed from western South Dakota before the Oligocene was doubtless much greater in western South Dakota. During deformation, or when buried under greater depths, the sandstone lenses were doubtless under greater pressure than at present, and if the water was partly expelled from them during the period of high pressures, the expansion of the sandstones and associated shales upon the release of pressure might reduce the head to such an extent that the wells could not flow. A similar theory has been advanced by Thom.[30]

Piper[31] also states: "Russell estimates the area within which the head has been lowered by the municipal wells at Aberdeen as 1,600 square miles, although his most extensive lentil is but 5 or

[29] Russell, W. L., *op. cit.*, p. 156.

[30] Thom, W. T., Jr., "Synclinal Oil Occurrence and Regional Uplift," Amer. Assoc. Petrol. Geol. Bull., May, 1928.

[31] *Op. cit.*, p. 695.

10 miles in maximum dimension." This statement is a misquotation, as no such statements were made in the writer's original paper. The 1,600 square miles is an arbitrary assumption made for the purposes of calculation, and no statement that the most extensive lentil is but 5 to 10 miles in maximum dimension is made in the paper.

Conclusion.—The resultant effects of hydraulic circulation and of compression and compaction in disconnected sand lenses are unfortunately quite similar. However, in every case where the results would be expected to be different, the actual conditions are what would be expected if the artesian pressure were produced by the compression of disconnected sand lenses. In other words, there are several unanswerable arguments in favor of the compression-compaction hypothesis, and none in favor of the old artesian theory. It is true that the exact nature of some of the processes, such as the dilution of the salt waters, is not definitely known, but this in no way detracts from the value of the theory, nor does it weaken the evidence favoring it.

W. L. RUSSELL.

EASTLAND, TEXAS.

ORE GOES WHERE IT CAN.

Sir: Structure may be divided into two types: major and minor. Of minor structure—fracturing, faulting on a small scale, bedding planes, or vesicles,—much has been written and its importance in ore localization has been duly emphasized. Of major structure in this connection we are hearing more in recent years. Deep-rooted earth-slips and jointings, upwarpings and downwarpings involving important fractions of the earth's crust, isotatic adjustments, orogenic movements, these and others will increasingly occupy the attention of the members of our profession who are seeking the ultimate source of ore.

We have been in the habit of saying that ore is where it is because two fractures intersect; because a fault movement has brecciated the walls; because a certain rock is favorable for replacement; because earth stress has opened up a series of parallel

tabular open spaces. But it should be emphasized that (1) ore would exist at that particular locality regardless of these favorable features, *providing the structure were conducive,* and (2) ore would normally not exist there, *providing the structure were unconducive.* And by structure is meant major structure: major structure is the meat of the matter.

The concensus of opinion (at least in America) on the genesis of ore deposits favors the differentiation theory. In fact, the belief that the greater portion of the precious and semi-precious metal deposits have been derived from igneous rocks by some differentiation process has become so thoroughly established that it is no longer regarded as a theory but is accepted as a working fact. Taking this for granted, it is logical to infer that such metallic-compound differentiation products have existed and still exist at certain points below the earth's surface, probably at considerable depths. Providing there has been no subsequent horizontal migration, these points are the *loci of differentiation.* Providing there has been, the ore-differentiate or magma will be found at the *locus of horizontal injection.*

Ores so differentiated from a magma, either in place or horizontally migrated, will remain at that site—assuming no upward movement by gnawing at the roof—until favorable structure affords them egress. Fractures in the earth crust produced by tension or compression, or strain without rupture which the ore solutions under differential pressure are able to break down, cause the "juices", under pressure, to rise, though the horizontal component of the direction of movement may be relatively great. They will rise as far as favorable structure permits them, and may ascend well up into the upper crust, even to the very surface.

The possibility that a terrain may have no ore deposits because solutions rising below it have issued at the surface without depositing their metallic load must not be overlooked. This may well have happened on occasion, though, being at the extreme of the range of perhaps equal possibilities, its chance of occurring is rare. Oftener the case will result of the ore solution depositing part of its load below the surface, while the remainder of the

metallic content either reaches the surface or joins the general underground circulation. The quantity of metal that is precipitated at the surface and below depends upon such factors as the chemical equilibrium of the solution and the wall-rock, the temperature of the solution, the physical nature of the channelway and of the wall-rock, the mixing of two or more solutions, and others frequently mentioned. If the solution does not sufficiently cool (as through too rapid ascent), if it does not react with the walls, and does not mix with another solution of different composition, if, in short, no influence causes precipitation, then it may debouch from its channelway, and deposit much of its load, both metal and gangue, at the surface.

There is of course the possibility that ore solutions may dissolve their way upward, either depositing as they rise or limiting their precipitation to the upper horizons. An eminent petrologist has demonstrated that in certain intrusive terrains, where cross-cutting relations are to be found, magmatic stoping has occurred. An eminent mining geologist regards many ore solutions as ore-magma splits from a parent magma. May not the ore magma stope an ascent for itself?

Of such ore-magma stoping in a rough survey of some of the principal described deposits one sees little evidence. Very commonly it appears that major structure is in control and that without major structure ore deposits would not be where they are.

R. D. HARVEY.

MOROCOCHA, PERU.

REVIEWS

Geologie des Chicamatales in Nordperu und seiner Anthracitlagerstätten (Geology of the Chicama Valley in Northern Peru and its Anthracite Deposits). By RICHARD STAPPENBECK. *Geol. und Pal. Abhandl.*, Neue Folge, Bd. 16, 4, pp. 307–355, 1929. 5 plates, 4 colored maps and sections.

The author is well known to students of South American geology through his numerous excellent contributions to the subject, notably his Map of the Mineral Deposits of South America. This paper presents the results of a study of the geology of the Chicama Valley in 1918 and 1920 in connection with an investigation of the water resources of the lower valley and the coal deposits of the upper valley for the well known Peruvian commercial house of Gildemeister and Company. It presents the geology of the Chicama Valley from the Pacific Coast to the summit of the western range of the Andes. Reconnaissance observations in the upper part of the range were extended northward across the next valley, that of the Jequetepequete River, to Cajamarca and southward to the adjoining valley of the Moche River.

The geology of the high Andes between latitudes 10° to 13° S. was described in 1924 in an excellent paper in the Bulletin of the Geological Society of America by D. H. McLaughlin. The geology of the Andes from Chimbote to the Huallaga River in about latitude 9° S. was studied in 1924 by the Ellsworth Expedition of The Johns Hopkins University, the results of which are in preparation for publication. This survey followed the Santa River on the western slope. The next valley to the north is that of the Moche River, in which are located the operations of the Northern Peruvian Mining and Smelting Company in the Salpo, Milluachaqui, Quiruvilca, and Callacuyán districts. Paralleling it on the north in about latitude 7½° S. is the Chicama Valley. North of Cajamarca there has been no comprehensive study of the Peruvian Cordillera and little is known about its geology. The northern coastal region, in the oilfields, has been described in a number of excellent contributions of recent date of which the most comprehensive is that by T. O. Bosworth. The main features of the geology of the eastern Andes, the reviewer has described in two papers in the Bulletin of the Gological Society of America in 1927 and 1928. This résumé of recent contributions to the geology of central and northern Peru is given to emphasize how much remains to be done and how welcome such a contribution as Stappenbeck's is to the student of Peruvian geology. Also, those familiar with

this literature will find even greater interest in comparing the corresponding geologic features of these areas.

Two geologic maps, one of the lower and one of the upper portion of the Chicama Valley, on the scale of 1 to 250,000 and 1 to 200,000 respectively, show the areal geology. The coastal portion of the first map shows mainly unconsolidated materials embracing four terraces, river alluvium, sand dunes and outwash debris. Projecting out of these are numerous isolated hills and groups of hills of the underlying rocks. They consist of plutonic rocks of granitic nature, but with more basic peripheral facies, associated aplitic and lamprophyric dike rocks, and volcanic rocks ranging from dacite to porphyrite in composition. On the coast itself are two small areas of quartzite and phyllite of unknown age which correspond to the Silla de Payta and the Cerros Illescas further north.

As soon as the coastal plain is crossed, at a distance of about 16 miles inland, and the foothills of the Andes are entered, Tithonian and Wealden strata occupy extensive areas between the igneous rocks. They have been intruded and metamorphosed by the plutonics. Stappenbeck says the contact metamorphism is not as extensive as one would expect from the size of the intrusions. His account of the contact action leaves the impression that it is much less intense and less extensive than I observed it in the Santa Valley and the Cordillera Negra further south.

The map of the lower valley extends 36 miles inland. There follows an hiatus of about 12 miles between its upstream boundary and the western edge of the map of the upper valley which begins at Tambo. This map extends 33 miles further into the Andes. It includes the Huayday coal field. There are many intrusions of both plutonic and volcanic rocks in the upper Chicama Valley, but igneous rocks are less conspicuous than in the lower valley, and the terrane is predominantly one of sedimentary rocks ranging in age from Jurassic Tithonian to Cretaceous Vraconian. Outside of the mapped area the Cretaceous beds extend up to Emscherian time.

The Tithonian strata are dominantly blue-black shales with intercalations of sandstone, but they include horizons of other colors. The same lithologic facies is developed in the Santa River drainage, along both the Santa River and its northern tributary, the Chuquicara River. On the other hand rocks of this age in the Cerro de Pasco region are described as limestones.

Overlying the Tithonian are three groups of Cretaceous Neocomian strata which Stappenbeck has mapped as Wealden, Pallares shale, and Ferrat quartzite. Fossils establish the Valanginian age of the Pallares shale. No fossils were found in the Ferrat quartzite, but it is overlain by fossiliferous beds of Aptian age. The Wealden is the coal-bearing horizon. It is made up of a lower quartzite which contains the coal beds.

an intermediate shale horizon, and an upper quartzite. The Neocomian quartzites give rise to rugged topography throughout the Andes of central Peru. This lithologic facies of the Neocomian extends southward through the Santa Valley region, Cerro de Pasco, and at least as far south as the Jatunhuasi coal field. The Pongo quartzitic sandstone, which I have traced from the Pachitea River in the eastern Andes to the Ecuadorean border and which Sinclair and Wasson found far up into Ecuador, is of the same age as these quartzites.

Overlying the Ferrat quartzite is a succession of prevailingly calcareous beds representing the time from Aptian to Emscherean, that is, from upper Neocomian, through Albian, Cenomanian, and Turonian, into lower Senonian time. Stappenbeck gives as the total thickness of Cretaceous beds deposited on the Wealden 3,000 m., of which less than 1,000 m., perhaps only 500 m., represents Pallares shale and Ferrat quartzite. Hence these calcareous beds have a thickness of over 2,000 m. Though limestone is a dominant feature the strata include much shale, sandstone, and quartzite. The same lithology extends into the Santa River region. McLaughlin's Machay and Jumasha limestones are the time equivalents of these beds. It appears from a comparison of McLaughlin's descriptions of their lithology with Stappenbeck's descriptions and my own observations in the Rio Santa area, that limestones constitute a greater percentage of the section in the Cerro de Pasco region than they do further north. Their estimated thickness in the Cerro de Pasco region is over 3,500 feet. My Cretaceous Shale-Limestone Series of eastern Peru occupies the same time interval, and those beds correspond to the Napo limestone and shale of Sinclair and Wasson far up in eastern Ecuador. The concordance in the upper and lower time limits of this long period of calcareous sedimentation over so vast an area is striking. Paleontologic evidence in the Chicama region establishes the interval from Aptian to Emscherean; in the Cerro de Pasco region from Aptian to Senonian; in eastern Peru from Albian to Coniacian; and in eastern Ecuador, a little more restricted range, from Albian to Turonian. In all of these areas, with the exception of the Chicama Valley region, the Cretaceous limestones are overlain by red beds. Whatever sediments younger than Emscherian were deposited in the Chicama region have been eroded.

In view of the economic importance of the structure of the upper Chicama Valley, the tectonic features are described in considerable detail and presented graphically in 10 colored structure sections. The general structure is a succession of northwesterly trending folds with the anticlinal axes pitching to the southeast. Probably due to increasing elevation as the crest of the range is approached, the strata older than the Wealden outcrop mainly in the southwestern part of the area, and the limestones younger than the Ferrat quartzite occupy larger outcrop areas

in the northeastern part. The folds are asymmetrical with their steep sides to the northeast and are commonly overturned and often overthrust in that direction. Stappenbeck ascribes the anthracitization of the Wealden coals to the combined effects of weight of overlying sediments, intense folding, and igneous intrusion.

The Upper Chicama Valley comprises what is generally known as the Huayday coal field. Despite the small amount of development work that has been done and the meager published data, it has long been regarded as one of the most promising coal fields of Peru. This optimistic opinion has been based partly on its relatively easy accessibility to the coast. One of the narrow gauge railroads that serves the sugar plantations and agricultural interests of the lower Chicama Valley extends to within about 12 miles of Tambo, the entrance to the field. It could easily be extended to serve for the transportation of coal. Stappenbeck says the Wealden contains 4, or possibly 5, seams of workable anthracite which locally attain to thicknesses of 6 meters. At only three places, Huayday, Baños, and Compín, has the coal been developed, and at these places to such a limited extent that actually proven tonnages are estimated at only a few hundred thousand tons. In the estimates of probable reserves, the thickness of workable coal is taken at 3 and 4 meters, which the author considers very conservative; and on the assumption of considerable continuity in the seams he arrives at the total of over 170,000,000 tons. Concerning the quality of the coal, the paper gives 15 new analyses from the immediate area, and 55 analyses, including many from contiguous areas, taken from Peruvian publications. As it is impossible to give these in detail, I have compiled the average of each group. The table gives these averages and the maximum and minimum for each constituent.

CHICAMA VALLEY COAL (STAPPENBECK).

	Average.	Minimum.	Maximum.
Moisture	3.95	2.35	6.41
Volatile Matter	5.58	2.03	13.99
Fixed Carbon	79.96	67.40	86.10
Ash	10.49	4.32	16.80
B.T.U.	13088	11751	13601

NORTH CENTRAL PERU COALS (PERUVIAN SOURCES).

	Average.	Minimum.	Maximum.
Moisture	5.54	0.15	15.50
Volatile Matter	11.29	1.11	38.90
Fixed Carbon	75.53	36.75	92.55
Ash	9.04	2.85	30.25
B.T.U.	13228	7783	14627

The analyses over the wider region show a great variation in both character and quality. The coals of the Chicama Valley show reasonable uniformity in character and quality and are a good quality anthracite. It should be noted, however, that the analyses are without descriptions as to exactly what they represent with respect to the seam from which they are taken.

Stappenbeck may be somewhat too optimistic in the assumptions upon which his estimates of possible reserves are based. Despite the extensive occurrence of coal in the Peruvian Andes, the output is confined almost entirely to the production of the Cerro de Pasco Mining Company and the Northern Peruvian Mining and Smelting Company for their own operations in the vicinity of the mines. No success has been achieved anywhere in Peru in producing coal for the open market.

The seams worked by the Cerro de Pasco Company run very high in ash and are unworkable a few miles from the mines. The coal is used because it is handy and because of the high cost of bringing in coal of good grade. Despite the location of coal mines along the Chimbote Railroad in the Santa Valley, the railroad in 1924 was using only imported coal and the mines were idle. The management of the railroad said the local coal as mined ran so high in ash that it was unusable. This may have been the fault of inexperience in mining and lack of equipment for proper preparation. However, the coal openings I saw in the Santa Valley were impressive as to the treacherous character of the coal in respect to both quality and lenticularity of occurrence. The data presented by Stappenbeck on the Chicama coals are sufficiently favorable, however, to warrant further investigation and prospecting of the area to determine whether the seams are continuous enough in their extent to make possible the production on a large scale of coal of the quality shown by the analyses.

A word of appreciation should be added for the generosity of Gildemeister and Company in permittting so much of a purely private report to be contributed to geologic literature.

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Geology of Reservoir and Dam Sites, with a Report on the Owyhee Irrigation Project, Oregon. By KIRK BRYAN. U. S. Geol. Surv. Water Supply Paper 597a. Pp. 72, pls. 10, figs. 5. Washington, 1929.

This paper contains two distinct parts. The first part is a brief but thorough discussion of the geological principles involved in the investigation of reservoir and dam sites, with numerous examples cited in proof

of the principles discussed. The second part is an application of these principles to a particular area.

The first part opens with a brief but pointed discussion of Engineering Geology. "Most books bearing the title 'Engineering Geology' are simply college textbooks designed to give engineering students those parts of geology that are most valuable and interesting to them." Certain exceptions to this statement are cited.

Under the heading of reservoir sites, the chief requisites are listed as a tight basin, a narrow outlet with strong foundations, spillway facilities, available construction materials, a low silting rate, ample water supply, and need for the stored water. The first five come within the field of the geologist's study.

The making of a reservoir involves a changing of the ground water relations in the vicinity. In a region with a high water table, "ground water storage" may add to the capacity of the reservoir under certain topographic conditions; with a different topography, the probability of leakage through the reservoir walls must be considered. In a region with a low water table, leakage through the bottom of the reservoir would present the more serious problem. In either case, it is important to determine whether the confining formation is soluble or loose, thus increasing the leakage, or whether it is tight or insoluble so as to make probable the closing of the original leaks by silting. Examples of both cases are cited. The presence of a perennial stream is no guarantee that the valley in which it flows would be tight if used as a reservoir; such streams may be perched, and the higher parts of the valley may leak badly.

Local leaky areas, if small, may be cut off, or perhaps sealed by pressure grouting. It is important to recognize and forestall such a possibility, "because remedial measures against leakage are seldom possible."

Under dam sites, the problem of foundation material is of first importance. Most dam sites are in narrow valleys, with sides or abutments of solid rock, but with an undetermined fill in the bottom. The thickness of this fill must be estimated, and invariably checked by thorough drill tests. In the bedrock, weakening structures, even though small, must be considered. Clay seams that, when wet, will act to lubricate "gliding planes" must be recognized. Many rocks are very much weakened when saturated; consequently laboratory tests of strength are not conclusive.

Leakage, through or around a dam, cannot be entirely eliminated, but if the possibilities of leakage are correctly recognized in advance, the leakage may be minimized and the danger forestalled. Isolation of leaky areas and pressure grouting are the usual precautions to be taken. The same considerations apply to abutments, except that the weight of the

dam does not enter the problem. Spillways and tunnels through which large volumes of water must be sent present the additional problem of erosion.

Part I closes with two short but excellent sections, headed "Qualifications of the Geologist" and "Relations of Geologist and Engineer." The need is stressed for a higher degree of accuracy than may be needed in ordinary areal geology, for although "a reasonable success in prediction is all that may be expected," the construction work will make the geologist's conclusions "subject to a rigid verification." The function of the geologist is contrasted with that of the engineer, and the need for intelligent teamwork is emphasized.

An excellent annotated bibliography of sixty-five titles closes Part I.

Part II. of this paper is really a separate publication, a report of areal studies in connection with the Owyhee Irrigation Project, in Oregon. In it are applied in detail many of the principles discussed in a general way in Part I. The report covers preliminary investigations made by the author, supplemented by later studies made by Professors Warren D. Smith and F. L. Ransome in areas immediately adjacent. It is well illustrated with photographs, maps and drill hole test records, and contains such topographic, petrographic and other detail as the particular problem required.

The two parts supplement each other very well. Part I. explains what to do; Part II. demonstrates how to do it.

STERLING B. TALMAGE.

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Geophysical Prospecting. Papers and discussions presented at meetings held at New York, February, 1928, and at Boston, August, 1928. Pp. 667. Illustrated. Amer. Inst. Min. & Met. Eng., New York, 1929. Price, $5.00.

The aim of this collection of papers is "to make available to the mining public sound information concerning the principles underlying the various [geophysical] methods now in active use [for the detection of buried structures], to provide examples of current practice and results, and to afford opportunity for specialists to publish recent achievements and to receive the benefit of criticism and discussion by their colleagues." (Preface.)

The volume contains two introductory chapters emphasizing the value of geophysical methods to the mining engineer, the bridge and dam builder and the searcher for ore. These are followed by 9 papers discussing the electrical methods employed in prospecting, 7 on magnetic

methods, 6 on gravity methods, and 3 on seismic methods. Nearly all the articles are critical descriptions of the methods outlined. They are abundantly illustrated with plans and sections, and many of them give specific instances of their success in discovering geologic structures. About half are followed by discussions which, in some cases, bring out more clearly than the articles themselves the precise views of their authors.

The book treats the subjects with which it deals in a technical rather than a popular manner. It should serve as an excellent text-book for those who are sufficiently versed in mathematics to read it understandingly. It is well printed and abundantly illustrated.

W. S. BAYLEY.

Oil: Its Conservation and Waste. By JAMES H. WESTCOTT. Pp. 213. Beacon Publishing Company, 25 Broad St., New York, 1928.

The subject of the conservation of oil involves consideration of so many other questions that the author has wisely limited himself to dealing with the waste caused by the improper handling of producing wells, and of oil after it has been brought to the surface. He discusses the conservation of oil due to the development of improved methods of refining, to the reduction of evaporation losses in storage, and to the greater use of natural gas as fuel, and in making natural gasoline.

By steering clear of the pit-falls that await the person attempting to deal with such questions as reserves, unit development of oil fields, restriction of wild-catting and similar vexing subjects, the author has succeeded in presenting a very clear and readable picture of one side of the topic.

W. V. HOWARD.

UNIVERSITY OF ILLINOIS,
URBANA, ILLINOIS.

A Series of Elementary Exercises upon Geological Maps. By J. I. PLATT. Thos. Murby & Co., London, 1929. Price, 1s. 6d.

A set of eighteen uncolored geological maps, accompanied by a few explanatory notes and some suggestive questions, furnishes opportunities for teaching students in elementary geology and engineering the principles of map-making and cross-sectioning, and affords abundant material for interpreting structure. The maps are furnished separately or in paper-bound sets. Single maps are priced at 1½d.

W. S. B.

BOOKS RECEIVED.

Geology of the Iron Ore Fields at Masugnsbyn (northern Sweden). By PER GEIJER. Pp. 39, figs. 9, chart. Sveriges Geol. Unders. Ser. C, No. 351, 1928. With summary in English. Stockholm, 1929. Price, 1.00 kr.

The Mineral Wealth of the Black Hills. By J. P. CONNOLLY and C. C. O'HARRA. So. Dakota School of Mines Bull. 16. Pp. 418, figs. 35, pls. 64, index. Rapid City, So. Da., May, 1929.

Of the numerous papers discussing the economic geology and mineralogy of this region, few have attempted to cover the entire subject and none of these are of recent date. This bulletin reviews the mineral productivity to date, discusses the probable manner of deposition of the ores, and deals with possibilities of future development. Much of the material used is hitherto unpublished.

Geography, Geology, and Mineral Resources of the Portneuf Quadrangle, Idaho. By GEO. R. MANSFIELD. Pp. 110, figs. 3, pls. 8. U. S. Geol. Surv. Bull. 803, 1929.

"Red Beds" and Associated Formations in New Mexico. By N. H. DARTON. Pp. xvi + 356, figs. 173, pls. 62. U. S. Geol. Surv. Bull. 794, 1928 (June, 1929).

A Study of Ground Water in the Pomperaug Basin, Connecticut. By O. E. MEINZER and N. D. STEARNS. Pp. 146, figs. 14, pls. 9, map. U. S. Geol. Surv. Water-Supply Paper 597–B, 1929.

Graphical Terrane Correction for Gravity Gradient. By D. C. BARTON. Pp. 12, figs. 7. U. S. Bureau of Mines, Technical Paper 444, 1929.

Topographic and Geologic Atlas of Pennsylvania: No. 5, New Castle Quadrangle. By F. W. DEWOLF. Pp. 238, pls. 18, figs. 17, maps. Price, $1.00. **No. 27, Pittsburgh Quadrangle.** By M. E. JOHNSON. Pp. 236, pls. 33, figs. 28, maps. Price, $1.00.

Continuation of an excellent series giving geography, formations, and mineral resources; good maps.

Indragiri en Pelalawan. By K. A. F. R. MUSPER. Pp. 245; 24 large colored maps. Landsdrikkerij, Weltevreden, 1928 (April, 1929).

General geology, structure, economic products of this part of Dutch East Indies. Excellent structure maps. Written in Dutch.

Economic Outlook for the Basic Industries of Pennsylvania. 22 pp. Pennsylvania State College Bulletin, 1929 (April).

Thoughtful discussion of relation between resources and mining students.

Geological Survey of Great Britain, Summary of Progress, 1927, Part II. London, 1928 (May, 1929). Price, 65 cts., at the British Library of Information, 5 E. 45th St., New York.

Terminology in Coal Research. By R. THIESSEN and W. FRANCIS. Pp. 27, figs. 15. U. S. Bureau of Mines, Tech. Paper 446, 1929.

Metallurgical Limestone: Problems in Production and Utilization. By OLIVER BOWLES. U. S. Bureau of Mines, Bull. 299, 1929.

Canada Geological Survey, Summary Report, 1927. Pub. No. 2162. Part A. Pp. 63, figs. 6, maps 2. Also Part B, Pub. No. 2172. Pp. 94, figs. 4. Ottawa, 1928 (June, 1929).

The Bituminous Sands of Alberta. Part III. Utilization. By K. A. CLARK. Scientific and Indus. Research Council of Alberta, Rept. No. 18. Pp. 33, figs. 2. Edmonton, 1929.

Canada Dept. of Mines, Rept. for 1927–28. Pub. No. 2182. Pp. 61. Ottawa, 1929.

The Molding Sands of Maryland. By D. W. TRAINER, JR. Pp. 89. Part I. of a series inaugurated by the State Geol. Survey of Maryland to determine the possibilities of finding molding sand deposits in coastal plain formations.

Mining Industry of Idaho, Thirtieth Annual Report, 1928. Pp. 270, illus., index.

Southern Rhodesia Geological Survey, Report for 1928. By H. B. MAUFE, Director. Salisbury, 1929.

Metallization from Basic Magmas: A theory of genesis for hydrothermal and emanation types of ore deposits. By C. D. HULIN. Univ. of California Pub., vol. 18, no. 9, pp. 233–284. Berkeley, 1929.

SCIENTIFIC NOTES AND NEWS

R. J. Colony, of Columbia University, New York, is giving a course in geology at the summer school of the University of Wyoming, Laramie, Wyo.

H. Foster Bain, secretary of the A. I. M. E., was one of four members of an international committee that visited Colombia recently to study the subject of oil legislation in that country.

B. S. Butler, of the U. S. Geological Survey, has been engaged in the completion of mapping work in the Alma district, Colorado.

A. P. Coleman and E. L. Walker, of the University of Toronto, Canada, are attending the International Geologic Congress in Pretoria.

H. Salfeld, professor at Göppingen, Germany, recently lectured before the Colorado Engineering Council on "Recent Results of Seismic and Electrical Prospecting."

George Otis Smith, director of the U. S. Geological Survey, is a delegate to the World Engineering Congress, which will meet at Tokio this fall.

H. G. Ferguson, of the U. S. Geological Survey, is doing field work in western Nevada in coöperation with the State Mining Bureau.

E. W. Shaw is now connected with the Turkish Petroleum Company of London as chief geologist.

James M. Hill, of Berkeley, Calif., is now consulting geologist for the North American Mining and Smelting Corporation.

Victor C. Heikes, formerly engaged in work on mineral resources at Salt Lake City, Utah, is now in charge of the Mineral Statistics Division of the U. S. Bureau of Mines at San Francisco, succeeding James M. Hill, resigned.

Richard M. Hunt, of Salt Lake City, Utah, who has been spending several months in Jalisco, Mexico, is now in Europe and will return about Sept. 15.

Guy C. Riddell, of New York City, has returned from a trip to Mexico and Yucatan.

R. E. Tuck, of Toronto, Canada, has been appointed geologist and engineer in charge of the Sudbury Lode Mines, in northern Ontario.

J. R. Thoenen, of the U. S. Bureau of Mines, is investigating the commercial development of alunite and leucite for potash, on a field trip through the South and Colorado, Utah, and Wyoming.

J. T. Pardee, of the U. S. Geological Survey, is undertaking, in cooperation with the State, a survey of the mineral deposits of western Oregon.

Victor Dolmage has resigned as director of the British Columbia office

of the Canadian Geological Survey to join the firm of Stewart, Batten & Associates, as consulting geologist.

L. B. Snider, formerly with the Amerada Petroleum Corporation, is now connected with the geological department of the Producers and Refiners Corporation, Tulsa, Okla.

G. A. Muilenburg, of the Missouri School of Mines, is spending part of the summer in examining mineral deposits in West Texas, New Mexico, Utah, and Wyoming.

The Geological Society of New Mexico, recently organized, elected officers as follows: Walter B. Lang, U. S. Geological Survey, president; Frank Prout, Empire Oil & Gas Co., vice-president; Burton Headley, Southern Petroleum Exploration, Inc., Roswell, secretary; Morgan J. Davis, Humble Oil & Refining Co., treasurer.

The Fort Worth Geological Society has elected for the year 1929 the following officers: R. A. Liddle, president; A. R. Denison, vice-president; C. E. Yager, secretary-treasurer.

The San Antonio Geological Society, recently organized, has elected the following officers: Charles H. Row, president; R. F. Schoolfield, vice-president; Kenneth Owen, secretary-treasurer.

The Alberta Society of Petroleum Geologists, organized last January, held its first annual meeting at Edmonton, March 1 and 2, and announced the following officers: Theo. A. Link, president; P. S. Warren, vice-president; H. M. Hunter, secretary-treasurer; B. F. Haske, business representative.

The 25th Annual New England Intercollegiate Geological Excursion is set for Friday and Saturday, October 11 and 12, in the Fifteen Miles Falls area, with headquarters at Thayer's Hotel, Littleton, N. H.

The Director of the Rosenwald Industrial Museum, which is to be located in the Fine Arts Building at Jackson Park, Chicago, Ill., has sent out from the Museum Office, 300 West Adams Street, a request for information as to any pieces of apparatus of historic interest that might fittingly be placed in this first industrial museum of America.

The Association of Engineers of Liege, Belgium, in conjunction with the Geological Society of Belgium, have sent out a preliminary notice of the Sixth Session of the International Congress of Mines, Metallurgy and Applied Geology, to be held for about a week commencing the last of June, 1930. Further details of the Congress will be announced later by the Secretary General, Monsieur O. Lepersonne, Association des Ingenieurs, 16 Quai des Etats-Unis, Liege, Belgium.